U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB-276 811

Disposal of Hazardous Wastes. Landfill

NATO Comm on the Challenges of Modern Society, Brussels, Belgium

May 77

PB 276 811

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. NATO/CCMS-64	2.	3. Recipient's Accession No. PB-276 811

4. Title and Subtitle

Disposal of Hazardous Wastes. Landfill

5. Report Date
May 77

6.

7. Author(s)

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

NATO Committee on the Challenges of Modern Society
Brussels (Belgium)

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.

(C)

(G)

12. Sponsoring Organization Name and Address

13. Type of Report & Period Covered

14.

15. Supplementary Notes

Report prepared by the United Kingdom. NATO furnished.

16. Abstract (Limit: 200 words)

Contents: Landfill Practice--(Use of landfill, Selection and preparation of sites, and Site operation and methods of disposal); Landfill Research--(Current research in participating countries, and Site investigation techniques).
(Portions of this document are not fully legible)

17. Document Analysis a. Descriptors

*Hazardous Materials,	Ground water,	Sites,
*Solid waste disposal,	Surface water,	Leaching.
*Earth fills,	Water pollution,	
*Chemical compounds,	Air pollution,	

b. Identifiers/Open-Ended Terms

NATO furnished.

c. COSATI Field/Group 13B

18. Availability Statement National Technical Information Service Springfield, Virginia 22161	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 103p
	20. Security Class (This Page) UNCLASSIFIED	22. Price PC A06/MF A01

(See ANSI-Z39.18)

See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

ATTENTION

AS NOTED IN THE NTIS ANNOUNCEMENT, PORTIONS OF THIS REPORT ARE NOT LEGIBLE. HOWEVER, IT IS THE BEST REPRODUCTION AVAILABLE FROM THE COPY SENT TO NTIS.

Pilot Study

Disposal of Hazardous Wastes

Landfill

Report prepared by the United Kingdom

Committee on the Challenges

of Modern Society

North Atlantic Treaty Organization

May 1977

This report is printed on recycled paper

NATO/CCMS PILOT STUDY ON DISPOSAL OF HAZARDOUS WASTES

SUB-PROJECT ON LANDFILL

REPORT PREPARED BY THE UNITED KINGDOM, MAY 1977

CONTENTS

Page

SUMMARY AND RECOMMENDATIONS

I. INTRODUCTION 1
- 1. Project definition and objective 1
- 2. Method 1
- 3. Scope and content of this report 1

II. LANDFILL PRACTICE 3
- 1. (Use of landfill) 3
  - 1.1. The extent of use of landfill in participating countries 3
  - 1.2. Importance of preventing water pollution 9
  - 1.3. Some examples of water pollution problems caused by landfills 11
  - 1.4. Other possible hazards 15
- 2. Selection and preparation of sites, and 17
  - 2.1. Site selection 17
  - 2.2. Site preparation 22
- 3. Site operation and methods of disposal) 28
  - 3.1. Leachate control 28
  - 3.2. Methods of disposal 30

III. LANDFILL RESEARCH 41
- 1. Current research in participating countries, and 41
  - 1.1. Canada 41
  - 1.2. Federal Republic of Germany 48
  - 1.3. France 55
  - 1.4. Netherlands 59
  - 1.5. Norway 61
  - 1.6. United Kingdom 63
  - 1.7. United States 72
- 2. Site investigation techniques) + 79
  - 2.1. Preliminary site assessment 79
  - 2.2. Detailed site investigation 80

IV. CONCLUSIONS 82

REFERENCES 87

FIGURES

SUMMARY AND RECOMMENDATIONS

1. In summary, an attempt has been made to achieve the subproject objective, namely to assess the contribution that landfill and special chemical landfill can make to the safe disposal of some hazardous wastes. In the event, more information was received regarding the prevention of water pollution hazards than from air contamination.

2. The report contains but a small part of the considerable amount of valuable information provided by the contributing countries. The more important points have been gathered together in Section IV but reference should be made to the previous sections for more detail, and then if necessary to the original papers.

3. Considerable attention has been paid recently to the practice of landfill of hazardous wastes, and substantial investigational work carried out; as a result the subject is becoming better understood. However, much research is still in hand or is planned and it is felt to be important that the results should be made available for evaluation by all member countries.

4. In the meantime sensible landfill and special chemical landfill of some hazardous wastes seems likely to be accepted as a part of the general disposal concept in almost all participating countries, although being implemented to varying degrees.

5. It is considered that, for the future, attention should be paid in particular to continued work on

   i. operating procedures for the landfill of hazardous wastes, including air contamination aspects,

   ii. the field-study of recovery and attenuation mechanisms in existing landfill sites,

   iii. the smaller-scale research work on the interactions of hazardous wastes and leachates with domestic waste, and with various soils and rocks, and

   iv. site selection and engineering criteria.

I. INTRODUCTION

I.1. Project definition and objective

I.1.1. Definition

To ascertain the extent to which technical study is being made in participating countries of how landfill and special chemical landfill can safely be used for the disposal of hazardous wastes, and to exchange views and information on these studies.

I.1.2. Objective

To assess the contribution that landfill and special chemical landfill can make to the safe disposal of hazardous wastes, having regard primarily to the prevention of both ground and surface water pollution hazards, but also of air contamination.

> Note: "Landfill" in this report means the co-disposal of hazardous wastes with domestic or other wastes and the separate disposal of hazardous wastes (special chemical landfill)

I.2. Method

I.2.1. Participation

This project is a constituent of the NATO/CCMS Pilot Study on Disposal of Hazardous Wastes. Countries which participated in the project were: Belgium, Canada, Denmark, Federal Republic of Germany, France, Netherlands, Norway, United Kingdom, and United States of America. The United Kingdom acted as project leader.

I.2.2. Meetings

During the pilot study period the following meetings were held:

Date		Location	Meeting Status
September	1973	Bonn, Federal Republic of Germany	Experts
September	1974	Munich, Federal Republic of Germany	Experts
June	1975	Ottawa, Canada	Plenary
October	1975	London, United Kingdom	Experts
May	1976	Bonn, Federal Republic of Germany	Plenary
May	1977	Washington DC, United States of America	Plenary

The Experts Meetings consisted of specialised technical discussions and visits relevant to particular projects; at the Plenary Meetings progress reports from each project were received.

I.3. Scope and content of this report

I.3.1. It was agreed that the project should be dealt with under two main headings (a) landfill practice, and (b) landfill research, including the extent to which hazardous wastes are disposed of by landfill. The scope of each of these main headings was outlined by the United Kingdom in its presentation at the Bonn Meeting (1), although in the event the form of this report has been slightly modified from that intended earlier.

I.3.2. Contributions for inclusion in this report were received from the following countries: Canada, France, Federal Republic of Germany. Netherlands, Norway, United Kingdom and United States of America. Such information as was available from other participating countries has been included; this was based mainly on their presentations at project meetings or on papers submitted to the project leaders.

II. LANDFILL PRACTICE

II.1.1. The extent of use of landfill in participating countries

II.1.1.1. CANADA

In Canada, municipal and industrial solid waste management, including land disposal, is generally a private sector or local government responsibility carried out under enabling Provincial Government legislation and regulation. The Federal Government has no applicable enabling legislation for dealing with such matters, except in isolated instances where wastes are spilled or directly discharged into surface waters. The Federal Government's role is principally to develop solid waste management technology, to generate and evaluate technical solid waste management information, and to develop new or improved guidelines or codes of good practice relating to various waste management aspects. These activities are conducted on a national basis as a service to the public and as a back-up to the regulatory agencies.

Many factors have contributed to an emergence of differing approaches by Provincial Government regulatory agencies towards the regulation of waste management practices. Such factors include: widely varying physiographic and climatic conditions across Canada; the availability or lack of information on present practices; regional land use conflicts; and public attitudes. While landfilling is widely used in Canada for the disposal of both municipal and industrial wastes, industrial waste management systems employing either deep well disposal, liquid waste reprocessing and reclaiming, and/or incineration operations are available, but are currently being under-utilised. The increased use of these systems will be mainly dependent on the development of hazardous waste management legislation and/or regulations at the various levels of Government in Canada.

II.1.1.2. DENMARK

Landfill is used for municipal and industrial waste, chemical and hazardous waste being treated at a central municipally-owned plant (Kommunekemi) with facilities for incineration, chemical treatment etc. Residues from this plant will be disposed of at a special landfill site.

II.1.1.3. FRANCE

The public system of industrial waste disposal at present being established in France consists mainly of treatment plants combining an incineration process and a physicochemical neutralisation unit for liquid and solid waste. Although much industrial waste has been deposited at private sites (see III.1.3.2.(a)), landfilling of this type of waste has not yet been integrated into an overall waste disposal system. Thus both in the public treatment plants now in operation in Alsace and in the Paris region, as well as the 2 other centres planned to come into operation shortly in the Lyons region and in Basse-Seine, the problem has only been considered from the point of view of storage (using different techniques) of the sludges left after processing.

However, in considering the need to optimise the system of official waste disposal in France as a whole, landfilling of certain categories of industrial waste is increasingly being regarded as a wholly acceptable means of disposal.

In fact it seems preferable where possible to deposit certain wastes in controlled landfills rather than to incinerate them or treat them in a physicochemical process, which often leads to abnormal energy requirements (incineration of wastes with a very low heating value) or to pollution transfers (atmospheric emissions or production of toxic sludges, for example). Furthermore these processes are more costly, whereas landfill may well be the most economic solution in many cases.

Nonetheless it is clear that many questions remain to be answered before permits for landfill disposal of industrial wastes can be granted. In particular it will be necessary to have a precise definition of the wastes which can be landfilled and the methods of operation to be used at sites receiving industrial wastes, ie site development, possible means of supervising the wastes, use of site (operating plan enabling the stored wastes to be located at a later date) or longterm supervision.

II.1.1.4. FEDERAL REPUBLIC OF GERMANY

Landfill is an important disposal method for most types of waste arising in the Federal Republic of Germany, and sites are specifically designated according to their suitability for different waste categories:-

a. Municipal landfills, at which predominantly domestic and commercial wastes are deposited. Hazardous wastes are rarely accepted for co-disposal, and in general liquid wastes of any provenance including liquid sludges are not accepted.

b. Multi-component landfills, primarily for co-disposal of domestic, commercial and compatible industrial wastes, where hazardous wastes may be accepted under special conditions.

c. General industrial waste landfills, where a variety of industrial wastes, but not domestic waste, are jointly disposed of.

d. Mono-component landfills, operated by particular industries, co-operatives or municipalities, for disposal of wastes which because of their quantities, properties or potential for recovery require them to be kept separately from other wastes.

e. Special waste disposal facilities, mainly for difficult and hazardous wastes, and incorporating facilities for chemical treatment, incineration etc, with provision for landfill disposal of residues.

Approximately 20 million tonnes of domestic and trade waste are generated annually in the Federal Republic of Germany, and the estimated annual quantity of process-specific special waste is approximately 3 million tonnes*. Certain hazardous wastes, such as cyanides and used hardening salts, cannot be landfilled and may be disposed of only at a specified deep mine. In 1975 some 75% of all domestic waste was landfilled at about 4,000 sites; according to Waste Management Plans of the Lander only about 500 sites will remain in operation by 1980. The Federal Government is responsible for enacting legislation relevant to water protection (framework responsibility) and waste disposal, but implementation and enforcement of these measures is the responsibility of the individual Lander. The main instruments of legislation are:-

---

*Since the classification of hazardous waste varies between the participating countries, these estimated quantities cannot be directly compared.

i. the Water Resources Management Act 1957, as amended until 1976;

ii. the Disposal of Wastes Act 1972, as amended in 1976 and published in 1977.

The former Act regulates inter alia the introduction of materials into surface and groundwaters, and specifies conditions for the storage and deposition of materials liable to contaminate waters. The Waste Disposal Act includes inter alia provisions on planning and licensing of facilities, control measures and waste disposal organisation. Under this Act, hazardous wastes are not specifically defined although the 1976 amendment includes a provision enabling the Federal Government to issue a statutory order enumerating particularly hazardous wastes which will be subject to particularly strict control measures. This order is to come into effect by 1 June 1977. Public authorities responsible for waste disposal are held to dispose of all wastes that can be properly disposed of in their facilities together with residential waste. Minimum requirement for the layout of waste disposal facilities is that they can cope with the residential wastes of the respective region. When a waste is excluded on the basis that it cannot be disposed of at the public facility, responsibility for its safe disposal rests with the producer of this waste. Both Acts incorporate a wide range of environmental protection considerations including aspects of health, safety, planning and amenity conservation using general clauses to protect public welfare.

II.1.1.5. NETHERLANDS

Disposal of waste to land is regulated from the viewpoint of environmental protection, especially with respect to groundwater resources which are of particular importance in the Netherlands. The relevant legislation will consist of:-

i. the Chemical Waste Act;

ii. the Waste Disposal Act;

iii. the Soil Protection Act.

Domestic, commercial and non-hazardous industrial wastes have to be disposed of in accordance with the Waste Disposal Act; hazardous wastes are controlled by the Chemical Waste Act. It is estimated (2) that approximately 10^6 tonne/year of chemical waste are produced, and the preferred methods of disposal for this quantity are: (a) regeneration and re-use, (b) treatment and incineration, and (c) special storage, including chemical landfill and storage in abandoned salt mines.

There is a general prohibition on disposal of chemical wastes on or in the soil, though in special circumstances (for example when the other preferred methods are unavailable) exceptions may be allowed, subject to stringent conditions. The requirements for such exceptions are not yet known, but it seems likely that chemical landfill will only be permitted when no emissions occur, and landfill co-disposal of chemical and municipal wastes will not be acceptable as a normal procedure. At present, no landfill sites specifically for chemical waste exist in the Netherlands, though eventually it is envisaged that up to 7% of the arisings of such wastes could be disposed of by this method.

For wastes other than chemical and hazardous materials, landfill disposal can be used if appropriate measures are taken to prevent contamination of* groundwater. In this respect, deposition of wastes below the water table or in surface water is not acceptable, and the recent legislation and recommendations have been based on this principle. Preferred practice is to deposit the wastes above ground level, thus forming a hill or mound rather than filling up an existing pit or quarry, and this practice has found support from recent experience in the Federal Republic of Germany. Compaction of wastes has been identified as an important factor in minimising generation of leachate and methods intended to promote surface run-off of incident rainfall, rather than percolation, are also recommended.

II.1.1.6. NORWAY

Although many areas of Norway are topographically unsuitable for use as landfill sites, there are however about 450-500 sites and other waste disposal facilities located mainly in the south-east of the country where the main concentrations of population and industry are situated. For climatic reasons, production of leachates at landfill sites is of particular significance. The estimated quantity of hazardous waste is about 120,000 tonnes/year, and at present only a small proportion of this (probably about 5%) is disposed of to land via municipal and private landfills. There are at present 4 special regional landfills for disposal of dewatered effluent treatment sludges containing heavy metals from surface treatment processes, and further sites are planned. The construction and operation of such special landfills are subject to control by state regulatory authorities, and deposition of wastes at these sites is controlled by a trip ticket system.

II.1.1.7. UNITED KINGDOM

Landfill is the most important disposal method for controlled waste in Great Britain, over 90% of the total quantities arising being disposed of in this way. The controlled waste includes approximately 18 million tonnes/year of household and commercial waste, 23 million tonnes/year of general industrial waste, and 3 million tonnes/year of building waste; other significant waste arisings include 12 million tonnes/year of power station waste, 60 million tonnes/year of mining waste and 50 million tonnes/year of quarrying waste. Co-disposal of various types of waste is often practised.

Wastes from quarrying and mining, power station waste and demolition waste, are mostly relatively inert, as is much of the general industrial waste.

---

*In many areas of the Netherlands, the groundwater table is within one metre of the level of the ground surface.

Some of these types of waste are used for such purposes as road construction or in building materials, whilst reclamation of materials, including energy recovery is increasingly being practised or considered for all wastes. The remainder, together with the major proportion of the domestic and commercial waste, is disposed of to land, mostly in association with land reclamation (which is another form of re-use). At present, disposal of controlled wastes is regulated, particularly with respect to licensing of landfill sites and disposal plants, by the Control of Pollution Act 1974, though until the relevant provisions of this Act are fully implemented the disposal of hazardous wastes is also subject to the provisions of the Deposit of Poisonous Waste Act 1972. Wastes from mining and quarrying do not at present come within the scope of the Control of Pollution Act, and their disposal is subject to the Mines and Quarries (Tips) Act 1969.

The proportion of controlled waste that can be regarded as hazardous, either because it contains indisputably toxic material or presents particularly difficult handling problems, is small. Probably only 1-2% (about 0.2 million tonnes/year) of the arisings of general industrial waste can strictly be classified as hazardous, although under the Deposit of Poisonous Wastes Act 1972 some 5 million tonnes/year of industrial waste is notifiable. Landfill disposal of such wastes is not precluded by present legislation, and the safe disposal of hazardous wastes has received particular attention both in the current UK Landfill Research Programme and from specialist sub-groups established by the Department of the Environment to examine and recommend on the whole field of arisings, treatment and methods of disposal for specific types of chemical waste.

The disposal of industrial waste to land contributes, as does that of domestic and commercial waste, to the reclamation of land, though more particular care may be needed to ensure that safe methods of handling are used and that adequate precautions are taken to prevent or limit water pollution. Landfill disposal of hazardous waste seeks to avoid, wherever possible, long-term problems due to the concentration or persistence of waste; instead reliance is placed on the "attenuate and disperse" concept, whereby factors such as chemical and biological degradation and processes such as dilution, adsorption and precipitation are allowed to play their part in rendering such wastes innocuous.

In 1972 a review of waste disposal facilities in England and Wales was undertaken as part of a survey to provide information for the planned reorganisation of responsibilities of disposal authorities. Although the results were not fully comprehensive, the survey showed that over 3,000 sites were then being used; many sites were probably used only for domestic and commercial wastes. Approximately two-thirds of the sites were owned by local authorities and the remainder by private operators. Following reorganisation of local government into larger units and introduction of policies of rationalisation, many small sites have since closed and relatively few new sites have commenced operations. More accurate estimates of the number of active landfill sites will become available from the information being obtained following the implementation of the site licensing provisions of the Control of Pollution Act 1974.

Recent UK legislation and guidance governing landfill is summarised below:

1. Deposit of Poisonous Waste Act 1972.

2. The Deposit of Poisonous Waste (Notification of Removal or Deposit Regulations 1972).
SI 1972 No 1017

3. Control of Pollution Act 1974.

4. The Control of Pollution (Licensing of Waste Disposal) Regulations 1976.
SI 1976 No 732
14 June 1976

5. The Control of Pollution Act 1974 (Commencement No 5) Order 1976.
SI 1976 No 731 (C21)
12 May 1976

6. Circular 70/72
Department of the Environment: Deposit of Poisonous Waste Act 1972.
19 July 1972

7. Circular 39/76
Department of the Environment: The Balancing of Interests between Water Protection and Waste Disposal.
13 April 1976

8. Circular 55/76
Department of the Environment: Control of Pollution Act 1974.
Part 1 (Waste on Land).
Disposal Licences
21 May 1976

II.1.1.8. UNITED STATES

Landfill is an important disposal method for both municipal and industrial waste. Approximately 18,500 sites accept municipal waste; many also accept industrial waste. About 120 million tonnes of domestic and commercial waste, and 240 million tonnes of industrial waste, are generated annually; of the industrial waste, approximately 90% is disposed of to land, and this quantity includes many potentially hazardous wastes.

As a consequence of the large geographical area of the United States, regional variations in climate and land use have influenced waste management policies to a greater extent than in other participating countries. The highest percentages of industrial hazardous waste arise in the Great Lakes, Gulf Coast, Mid-Atlantic and South-East States where large concentrations of heavy industry are located. These regions are generally characterised climatically by a net annual soil moisture surplus. In regions east of the Mississippi River, the average annual precipitation exceeds losses by evapotranspiration so that a net annual soil moisture surplus is typical. About 70% of the municipal waste disposal sites in the United States are located in such water surplus areas.

Legislation relevant to landfill disposal of wastes exists at both Federal and State government levels:

1. At Federal level, there is no regulatory control of land disposal of solid waste except for hazardous waste. The principal Federal regulatory legislation, which applies specifically to hazardous waste, is the Resource Conservation and Recovery Act 1976. This Act substantially amends and essentially replaces the Solid Waste Disposal Act of 1965, as amended.

This new Act empowers the Environmental Protection Agency (EPA) to issue regulations on the generation, transport, treatment, storage and disposal of hazardous wastes. The EPA believes that the preferred options for waste management should give priority to re-use and recovery of energy and materials, or to the treatment and destruction of wastes, before ultimate disposal methods such as landfill are used. However, for those hazardous wastes not amenable to any of the preferred options, secure disposal in a chemical waste landfill is mandated.

In addition, a Toxic Substance Control Act has recently (1976) been passed. This Act provides for the manufacture and use of any chemical substance to be regulated if the EPA find evidence that it presents an unreasonable risk to the environment; risks involved during the disposal of the substance may also come within the scope of this Act.

2. Under the Resource Conservation and Recovery Act, States will have the option to implement Minimum Hazardous Waste Regulations which meet Federal standards. The EPA will enforce the new law in non-complying States. At State level, all States have enacted legislation to control, in varying degrees, the health and environmental aspects associated with solid waste disposal. The scope and purpose of such legislation differs considerably between States; for example, while all States have implemented some type of control over municipal landfill sites, control of industrial sites is much less common and only a few States have specific legislation for hazardous wastes. Not all of the State legislation specifically deals with the prevention of water pollution from waste disposal.

II.1.2. Importance of preventing water pollution

II.1.2.1. As stated in the project objective, the risk of water pollution from disposal of wastes to land is regarded as the principal environmental implication to be considered in this study. Both ground and surface water resources could potentially be contaminated as a result of unsatisfactory landfill disposal, though in general the possible contamination of groundwater is regarded as the more important. The relative importance of ground and surface resources that are treated in participating countries for public water supplies is indicated in the following table:-

Country	Surface water %	Ground water (including spring water) %
Belgium	15	85
Canada	90	10
Denmark	2	98
Federal Republic of Germany	29+	71
France	52	48
Italy	7	93
Netherlands	30	70
UK	66	34
USA	81	19

+Including 20% represented by artificial groundwater replenishment and river bank filtration.

II.1.2.2. Risks of water pollution can arise when wastes buried at a landfill site come into contact with infiltrating rainfall, or with liquid wastes, resulting in the generation of a leachate which can have an obnoxious, highly mineralised composition. The movement of such leachate away from the landfill can then contaminate either surface or groundwater resources, unless the leachate is contained within the site for collection and treatment, or is attenuated and diluted and degraded by natural processes as it moves away from the site. Under the climatic conditions encountered in many of the countries*, especially in Europe and the eastern USA, it is virtually impossible to prevent completely the formation of a leachate, though its quantity and movement can be markedly reduced by adopting site operating methods designed to minimise leachate generation. When these climatic conditions are combined with a high natural groundwater table, as for example in the Netherlands, the scope for some mechanisms of leachate attenuation may be lessened because no significant depth of unsaturated strata exists.

II.1.2.3. The generation and movement of leachates are controlled by numerous factors which will vary in significance depending on the particular conditions of each case. These factors can be classified as follows:-

a. Site physical characteristics

geological
hydrogeological
climatic
engineering aspects etc

b. Waste characteristics

type
quantity
properties
method of deposition etc

---

*Such conditions being typified by a net annual soil moisture surplus, after allowing for evaporation, transpiration and surface run-off.

c. Local conditions

water supply - importance and use of aquifers
environmental impact
site redevelopment schemes etc

Most of these factors are considered in some detail in subsequent sections of this report.

II.1.3. Some examples of water pollution problems caused by landfills

The following examples taken from participating countries are intended only to illustrate the type of water pollution problems that can arise from landfill disposal of various wastes. Whilst in general they are probably representative of such problems, most of these and similar incidents appear to have been caused by such factors as bad site selection, unsuitable methods of deposition, and possibly by inadequate supervision at landfill sites. The relatively small number of cases of significant groundwater pollution supports the view that under suitable circumstances landfill disposal of various types of waste does not represent an unacceptable risk.

II.1.3.1. UNITED KINGDOM

Brief summaries of some water pollution problems caused by landfill sites in the UK were given in a paper presented at the London Meeting (3). Some additional examples (not necessarily involving hazardous wastes) are as follows:-

a. Mountsorrel Quarry, Leicestershire

Mixed wastes including food wastes and residues from manufacture of plasterboard, were deposited in a large partially flooded disused quarry in granite. After 3 to 4 years of operation, the site contained a large volume of contaminated leachate, which due to anaerobic decomposition of the food and sulphate wastes gave rise to obnoxious smells causing illness and inconvenience to nearby residents. Remedial measures involved cessation of deposition of the plasterboard wastes, and aeration and chemical treatment of the leachate to render it suitable for discharge to sewers. Deposition of domestic waste was later commenced to provide an absorbent medium which would enable the proportions of liquid and solid waste to be adjusted to a more acceptable value for satisfactory operation of the site. The remaining water is collected, treated and discharged separately to sewers.

b. Catthorpe Pit, Leicestershire

Domestic waste was deposited in a small pit from which clay had been extracted for road construction. Due to the local topography, and because the site had intercepted a complex system of field drainage from adjacent agricultural land, a depth of about 6 m of leachate collected at the base of the landfill. Supervision of tipping operations was also somewhat inadequate since the deposited wastes were not properly compacted and several fires occurred. To rectify the situation, a detailed drainage survey was undertaken prior to constructing a completely new system which diverted the field drainage away from the site. An improved site operating procedure was developed, using domestic waste to absorb any remaining liquid.

c. Dealers Barn Site, Kent

The site is located on hard fissured limestone and soft calcareous sandstone which locally constitutes an important aquifer. Disposal of various wastes, including significant quantities of predominantly notifiable liquid wastes, had been practised since 1955, though not in substantial amounts until 1967. Monitoring of groundwater composition, especially for concentrations of chloride and chromium, which would indicate contamination, using samples taken from boreholes located around the site showed the existence of a pollution plume extending a short distance away from the site in the direction of groundwater flow. Disposal of notifiable wastes was discontinued, and further boreholes constructed to investigate in detail the movement of contaminants away from the site. Results of the continued groundwater monitoring programme now suggest that a state of dynamic equilibrium has been reached between the leachate leaving the site and the effects of dilution by dispersion and by natural recharge of the aquifer, and the microbiological deterioration of the wastes. Thus although some degree of groundwater contamination has occurred at this site, natural processes have been effective in attenuating the concentration levels of contaminants in the leachate in the zone immediately surrounding the site.

II.1.3.2. UNITED STATES

A number of examples of problems caused by improper land disposal of hazardous wastes have been described by the Environmental Protection Agency (4, 5, 6) and some of these are given briefly below:-

a. Rocky Mountain Arsenal, Colorado

Infiltration of liquid industrial wastes, including chemical by-products from the manufacture of pesticides, herbicides and chemical warfare agents, from unlined storage basins caused extensive contamination of a shallow water table aquifer for distances up to 5 Km from the site. Several wells and other sources supplied from this aquifer had to be abandoned, and other environmental damage reported included losses of crops and livestock. Although the use of unlined storage ponds was discontinued in 1957, significant contamination of groundwater is still evident. Recently, a comprehensive project to study the feasibility of decontaminating the area has been proposed and based on the findings of this study a rehabilitation programme will be initiated.

b. Crosby, Texas

Disposal of acidic liquids and oily wastes into an unlined and disused sand pit caused local contamination of the aquifer and resulted in the temporary abandonment of several wells used for domestic water supply. The well water contaminants included abnormally high concentrations of manganese, zinc, iron and cadmium which originated from the disposal of acidic pickling wastes. Failure of a dike permitted contamination to reach the San Jacinto river on several occasions. Effective remedial actions have now been taken and the affected wells are again providing drinking water. The site itself is being infilled with soil from road construction programmes.

c. Dover Township Landfill, New Jersey

The Cohansey aquifer, a major groundwater source in the New Jersey coastal plain area, has been severely affected to an as yet undefined extent by petrochemical contamination caused by leakage from drums containing a wide variety of wastes which were disposed of at the Dover landfill site, or at a nearby farm. As a result of the contamination, the use of well water has had to be permanently abandoned within the affected zone, and alternative supplies have had to be provided. The extent of contamination of the aquifer, and the nature of remedial measures, have yet to be determined.

d. Cedar Valley, Iowa

Pollution of groundwater in the Cedar Valley aquifer, near Charles City, Iowa, has been reported recently due to infiltration of wastes containing arsenic from a chemical manufacturing company. Although at present there is sufficient hydrostatic pressure within the aquifer to prevent large-scale downward infiltration of contaminants, it has been found necessary to restrict significantly abstractions of groundwater from the aquifer within a radius of 15 miles for a period of up to 10 years.

II.1.3.3. FEDERAL REPUBLIC OF GERMANY

Some examples of groundwater contamination due to disposal of difficult wastes have been reported:-

a. Widdig (Northrhine-Westphalia)

Industrial wastes including effluent treatment sludges of varying composition containing inter alia minor amounts of ferrocyanide compounds were deposited in a disused gravel pit commencing in 1960 or 1961. In these alluvial strata of a Pleistocene terrace of the River Rhine, the water table was located at a depth of between 1 and 2 m beneath the base of the 10 to 12 m - deep pit. Water supply wells were located about 600 m from the site in the direction of groundwater flow. To monitor groundwater quality, a number of observation boreholes were constructed close to the site, and at greater distances between the site and the supply wells.

After some 2 years, cyanide concentrations up to 0.8 mg/litre were detected in the supply wells, but the cyanide was probably present in the form of less toxic complexes such as ferrocyanides and hexacyanoferrates, and could be reduced to safe levels by increased chlorination and use of activated carbon filters during water treatment. However it was considered necessary to remove the chemical wastes completely from the site in order to prevent further contamination of the groundwater.

b. Bochum-Gerthe area (Ruhr)

In 1970-71 a large number of drums containing heat-treatment cyanide waste were deposited without authorisation at a site used for disposal of building rubble, and overlying an important aquifer. It was estimated that about 500 tonnes of the waste, containing about 25 tonnes of cyanide (as CN^-) were dumped. Total cyanide concentrations up to 0.25 mg/litre were detected in surface streams close to the site, and ponds at the site itself contained up to 135 mg/litre. Although immediately below the disposal area very high local concentrations (up to about 1,000 mg/litre total cyanide) were detected the general groundwater quality had not been affected because of the protection afforded by the relatively impermeable subsoil and by the remedial measures that were instituted rapidly once the contamination had been detected (7).

c. Lauffen (Baden-Wurttemberg)

At the end of 1965 tipping of salt slags from aluminium melting and salt melting began in a 1.2 m deep brick clay pit near Lauffen. The infiltration into the loamy soil of precipitation waters containing dissolved chlorides led to an increasing hardness and chloride content of waters from 2 groundwater abstraction wells located downgradient from the tipping site. The effects became noticeable in July 1968, ie after a time-lag of 2½ years. The increasing hardness was caused by ion exchange reactions taking place in the soil. Calcium and magnesium ions were liberated by the heavy load of sodium and potassium in this landfill leachate. In the course of monitoring the wells the sodium content also increased with time and signaled the exhaustion of the ion exchange capacity of the soils with respect to sodium. It was estimated that the equivalent of 30 tons of NaCl were drained off via the 2 wells till 1972 (8).

d. Nievenheim (Northrhine-Westphalia)

On the premises of a zinc smelter at Nievenheim calcium arsenite/arsenate sludges and wastes from sulphuric acid production were treated in sludge drying beds over several decades. The solutions that percolated underground into an alluvial terrace of the river Rhine caused precipitation and enrichment of chemicals there, from which the groundwater continues to leach substances, partly in concentrations far exceeding the limits of WHO drinking water standards. Particularly high concentrations of certain heavy metals also arsenic up to more than 50 ppm and sulphate contents of more than 1g/l were found in the contaminated groundwater (9). There is also a marked difference in temperature between the pollution plume and the main groundwater, the plume being up to 12°C warmer than the groundwater. The plume although persistent, does not appear to move with the groundwater current, but the reasons for this behaviour are not yet fully understood.

e. Ratingen

Many tonnes of ammunition containing organic arsenic compounds were buried at Ratingen in 1918 in an area consisting of sandy soil. Some 40 years later a resident died apparently as a result of drinking water containing 6.5 mg arsenic/litre, obtained from a small new private well. Investigations showed that at a depth of several metres below ground level there was a contaminated plume of groundwater approximately 200 m long and up to 60 m wide. Concentrations of arsenic ranged generally from 1 to 10 mg/litre, with a value of 46 mg/litre in standing water in a well dug at the site of the original disposals. The uncovered poison gas ammunition had been lying partly in groundwater; as much as possible was removed.

Calculations based on analyses of groundwater and of random samples of soil suggested that the contaminated plume contained just over 1 tonne of arsenic mostly adsorbed on the sandy soil. Groundwater abstracted at the public waterworks at Ratingen some 650 m down hydraulic gradient of the disposal area showed only 0.01 mg As/litre. Monitoring continued until 1968, by which time it had been demonstrated that the arsenic plume travelling with the groundwater to the waterworks had achieved a high degree of dispersal at its foremost point some 400 m from the abstraction with a value of 0.02 mg/litre. Even within the plume values of below 0.06 mg/litre were measured.

II.1.4. Other possible hazards

Atmospheric emissions from certain types of hazardous wastes such as volatile organic compounds may also be important at some landfill sites, owing to the release of vapours from the wastes after their deposition. An example of this type of problem was reported by the EPA (6) to have resulted in the contamination of air, soil and vegetation over an area of about 100 sq miles in Louisiana, the most likely cause being the volatilisation of hexachlorobenzene and subsequent bio-accumulation of this substance in the affected area. The use at the landfill of thick coverings of soil and of polythene sheet is now being studied.

Experimental work carried out in the UK has shown that the evaporative behaviour of solvent mixtures deposited on landfill sites is difficult to predict, though the behaviour of individual components of solvent wastes was less complex. The deposition of liquids with a high volatile solvent content on to domestic waste increased the initial evaporation rate by a factor of 2 to 5 compared with that from a pool of liquid.

Volatile and less volatile water-miscible solvents (eg acetone and isopropanol respectively) appeared to evaporate less rapidly from domestic waste than from a pool of liquid, whilst volatile solvents dissolved in oil initially evaporate more rapidly from domestic waste, but at a rate which decreases substantially and may fall below that from a pool.

These findings suggest that release of vapour could in certain conditions present a short-term hazard to site operators as well as the public, but such risks would not persist for more than a few hours and could be minimised by suitable precautions during the disposal operations. However, since the relevant experiments were conducted only on a small scale, further confirmation (eg from tests carried out on a real landfill site) would be needed before definite conclusions could be reached. At sufficiently large sites, the risks (both to site operators and to the public) from discharge of solvent waste in limited quantities to the landfill would be small, particularly if this were done by means of a system of lagoons or trenches located well away from the main working face and making use of the absorptive capacity of the landfill materials, where co-disposal of solid and liquid wastes is permitted. Significant quantities of solvents are not usually landfilled now; other volatile wastes would need careful consideration if landfill is used and attention paid particularly to effective covering. Further research would be desirable on these aspects.

Reproduced from best available copy.

II.2. Selection and preparation of sites

II.2.1. Site selection*

II.2.1.1. Factors to be considered

Landfill is an important method of disposal for different types of waste, but acceptable application and operation depends largely on correct selection of suitable sites. In making such selections, many individual factors have to be considered, and their relative importance varies from site to site and from country to country. However, many participating countries seem to agree on the main principles which must be satisfied when selecting sites for landfills:-

i. Protection of the environment, especially the avoidance of unacceptable risks of significant contamination by leachate of surface and groundwater resources.

ii. Suitability for receiving particular types of waste.

iii. Eventual contribution to land stabilisation or restoration, ie use of largely derelict land to provide for future use for recreation, agriculture, forestry, and in some cases for commercial and industrial development (although in some cases there may be restrictions on these activities when hazardous wastes are included).

Site selection must also be made in the light of any relevant constraints, of which the following will usually be among the most important:-

i. Legislation; including the statutory requirements of local, regional and national governments.

ii. Site operating conditions; usually those specified by the authority responsible for controlling waste disposal operations.

iii. Technical and economic factors; especially the interaction of interests between waste producers, disposal authorities, and site owners and operators.

iv. Socio-political factors, especially public acceptance.

II.2.1.2. Site evaluation schemes

When the above considerations have been taken into account, potential sites for landfills need to be evaluated in terms of their individual characteristics. The geological and hydrogeological properties of sites will usually be the 2 most important physical factors, but other factors such as local climate, methods of operation value of land reclaimed, and types and quantities of waste are equally relevant for site evaluation purposes. At first sight it might be thought that the best approach to site selection would be to categorise wastes on the basis of their pollution potential (for example as measured by a leaching test), and to classify sites on the basis of their ability to contain wastes and leachates. Particular categories of waste could then be assigned to particular types of sites to produce definitive recommendations on waste disposal. Unfortunately, neither wastes nor sites lend themselves readily to such classification schemes, and for practical purposes a more generalised scheme capable of modification and adaptation to meet local requirements is needed.

---

*See also a complementary discussion of this topic in the report of the Sub-Project on Recommended Procedures for Hazardous Waste Management, carried out under the same NATO/CCMS Pilot Study on Disposal of Hazardous Wastes.

II.2.1.3. Practical applications

Several participating countries have begun to develop practical site selection schemes, and some examples of the approaches that have been used are given below:-

a. Canada: Soil-Waste Interaction Matrix Procedure (SWIMP)

An environmental assessment procedure, using a soil-waste interaction matrix, has been developed as a method for industrial waste disposal site suitability rating, and for site selection. The procedure consists of 2 matrices, (i) a site-independent and (ii) a site-specific matrix. The site-specific matrix is being constructed using columns of soil-site parameters, including a soil group, a hydrology group, and a site group, and rows of waste characterization parameters, including an effects group, a behavioural group and a capacity rate group.

The site-specific matrix may be used as follows. Matrix inputs are generated by determining parameter values for a given waste and given site in points or arbitrary units. These values are entered into the matrix, and waste parameter values are combined with soil-site parameters to provide matrix interaction elements. The sum of the interaction elements may then be used to provide an overall point score for comparison either with other point scores, or with a scale of arbitrary acceptability.

As a sub-set of this site-specific matrix, a site-independent matrix is also being developed. This matrix will possibly consist of columns of soil types and rows of waste composition parameters. In this matrix, a matrix entry will essentially be a soil attenuation factor which can be obtained either from the literature or through soil column leaching tests, such as traditional soil column work or batch dispersed soil-waste reactor work.

The final format for SWIMP is still being completed. Once finalised, SWIMP will be rigorously tested to determine its applicability and usefulness as a decision making "tool". A landfill site selection procedure has also been developed which is applicable for municipal waste disposal sites, but which could apply in part to industrial wastes as well; this procedure also uses a matrix format.

b. Federal Republic of Germany: Hessian Geological Survey Report (10)

Based on a study of the effects of waste deposition at sites in the Frankfurt area, the following conclusions relevant to site selection (though not with particular regard to hazardous wastes) were reached:-

1. Solid wastes should be disposed of at few but adequately sized and controlled landfills serving areas with more than 100,000 inhabitants. The area of the working face of the landfill should be kept as small as possible.

2. Wastes of all different kinds and sources should be co-disposed of, including slurries, sludges, oily wastes etc, which should be intimately mixed with the solids or deposited in thin layers or lenses.

3. In principle, wastes should be deposited above the groundwater table, and in the form of heaps rather than in pits.

4. Sites at localities with lower precipitation rates should be given preference over locations with higher rainfall, if such an alternative is possible (eg in mountainous areas).

5. The base of the landfill should be as high as possible above the water table.

6. Below the landfill and in the down-current area of groundwater flow, the cover strata (soils, sediments) should be of high absorption capacity and good permeability for water and gases, to allow for gas exchange between the atmosphere and the mechanisms of chemical degradation of contaminants taking place within the landfill. Where the geohydrological conditions are less favourable, lining and leachate drainage and treatment are advisable. Complete drainage and treatment will be necessary on impermeable strata.

7. Hydrologically favourable conditions are found where groundwater flow is slow (eg less than 1 m/day) and where attenuation capacity of the underlying strata is high.

8. Surfaces of deposits should have little inclination to avoid slumping, but sufficient to encourage run-off of surface water.

9. Where applicable, sites with saline groundwater unfit for usage should be preferred over other locations.

10. Groundwater at landfill sites should be monitored by means of boreholes.

11. Landfills should not be located in flood plains.

c. United Kingdom

A lithological classification scheme comprising 9 categories of geological strata in the UK was described in earlier papers (11, 12). This scheme has been applied to the selection of sites for detailed investigation in the research programme currently being undertaken.

For practical purposes, a simplified site classification scheme has been adopted:-

1. Sites providing a significant element of containment for wastes and leachates.

2. Sites allowing slow leachate migration but providing significant attenuation.

3. Sites allowing rapid leachate migration and providing insignificant attenuation.

By no means all sites will conform exactly to these 3 classes; for example many sites which provide an element of containment also permit the slow migration of leachates. However, the scheme is a useful guide and is capable of practical application if correctly used.

Class 1 sites (those providing a significant element of containment) are located on impermeable or relatively impermeable strata which contain wastes and leachates within the landfill or its immediate vicinity. Such strata include fine-grained compact rocks of low permeability, for example slates, shales and mudstones as well as soft clays and marls. The thickness of relatively impermeable strata required to provide adequate containment and to protect sensitive aquifers can be estimated from Darcy's Law, but such calculations do not take into account attenuation effects within the impermeable strata which are likely to improve the quality of leachate. There may also be an unsaturated zone beneath the site, which will delay the movement of the leachate front and further attenuate the contaminants before they reach the water table, though any abstraction of groundwater from aquifers underlying the landfill should be sufficiently distant to permit dilution and dispersion of any small volumes of leachate which slowly migrate from the site.

Although suitable for solid wastes, class 1 sites are not generally suitable for the disposal of large volumes of liquid wastes for 2 reasons: (a) there will be a tendency for a head of leachate to build up at the base of the landfill, and this will require a greater thickness of containing strata to prevent downward movement, (b) if disposal of liquids continues for longer periods the site will gradually fill up until the leachate may migrate laterally or spill over on the surface to contaminate streams etc. Thus clay pits relying principally on containment may be unsatisfactory for use as liquid waste disposal sites, since the end result will often be an extensive lagoon of contaminated liquid.

Class 2 sites (those which allow slow leachate migration) do not rely on containment, but allow leachates to migrate away at slow rates which permit natural processes to attenuate, dilute and disperse potential contaminants before they reach sensitive water resources. Favourable conditions for these processes to operate can be obtained by locating domestic waste disposal sites above a formation having significant adsorption or cation exchange capacity through which groundwater flow is intergranular. The presence of a relatively thick unsaturated zone is also advantageous for sites of this type since initially it will contain air which will enhance the development of oxidising conditions beneath the landfill. Groundwater flow through such a zone will also be slower than in the saturated zone.

Although intergranular flow is to be preferred, infiltration through joints and fissures could be acceptable provided that downward flow is sufficiently slow to allow time for fissure water to diffuse into static interstitial water. This is thought to occur in strata such as the Chalk in the UK, but is unlikely to occur in formations such as the Carboniferous Limestone. Thus in many regions landfill sites which offer excellent prospects for effective attenuation of domestic waste leachates (including those industrial wastes which produce a leachate of comparable composition) could be relatively easily identified from simple hydrogeological principles.

Class 3 sites (allowing rapid leachate migration) are those which provide neither containment nor significant attenuation. They may be located on a variety of geological strata, such as hard calcareous rocks in which groundwater flow is mainly through discontinuities widened by solution, or river terrace deposits with high water tables in which groundwater flow is intergranular. Such sites are normally suitable only for the disposal of relatively inert wastes, though local circumstances should be considered in each case so that optimum use is made of the available sites.

II.2.2. Site preparation

II.2.2.1. Use of Liners

The installation of impermeable liners at landfill sites is a comparatively recent development, and so far liners have not been used to any great extent in participating countries.

Application of liner materials to landfill sites may enable sites with otherwise unsuitable hydrogeological conditions to be used. However, the use of liners might in some cases prove disadvantageous if it resulted in the formation of a large volume of contaminated liquid due to the disposal of liquid industrial wastes or to retention of incident rainfall within the landfill.

Two principal techniques are available:-

a. treatment of base and walls of sites with an absorbent or impermeable substance;

b. installation of an impermeable membrane, usually made of a suitable synthetic material.

a. Wall/base treatment

The technique consists of treating the walls and base of the site with an impermeable or absorbent material, of natural or synthetic origin, which is either admixed with or applied directly to the site. Examples of natural materials used for this purpose are clay, puddled chalk, ground limestone and compacted fine-grained soil; synthetic materials have included concrete, asphalt and bituminous seals. In some cases, a natural material such as bentonite or montmorillonite layer has been used; the aim being to modify the composition of the leachate with a view to decontaminating it or rendering it simpler to treat subsequently.

b. Synthetic membranes

In this method, large sheets of suitable materials are used to cover the base and/or walls of the site before waste deposition commences. The types of materials that have been used include synthetic polymeric membranes such as butyl rubber, polyethylene and polyvinyl chloride, the sheets usually being joined together by mechanically or chemically formed seams.

In selecting lining materials for landfill sites, some of the more important considerations are as follows:-

i. Compatibility of the liner material with the type of waste to be confined. Leachates produced by certain types of waste are liable to cause deterioration of liners or seam materials, for example liners such as butyl rubber and asphalt would probably be damaged by wastes containing organic compounds such as hydrocarbons. Also, some impermeable materials can become permeable after prolonged contact with strong inorganic leachates containing for example acids, alkalis or brine solution.

ii. Physical properties of liner materials, including the effects of temperature and the method of installation. Successful application can depend on the civil engineering aspects of site preparation, and in particular on whether the lining material can be laid down without gaps or fractures which may subsequently fail and leak. Additional protection of liners (eg by layers of sand) may be needed. The physical properties of linings may also sometimes be affected by exposure to light and weather which in the case of some materials may render them brittle and easily liable to cracking.

iii. The degree of containment required and the lifetime of the lining material. Certain sites might, if a liner was installed, rapidly fill up with contaminated liquid which would present a hazard or require extensive treatment to make it suitable for discharge; the need to collect leachate has to be accepted as part of the scheme. The permeability of lining materials may vary as the materials age, and in fact some degree of permeability may be desirable in preventing the development of liquid-filled sites.

iv. When leachate is confined by a liner, a drainage network will usually be needed within the site to collect the liquid for subsequent treatment or possible recirculation. The latter process promotes more rapid development of an active bacterial population within the site and increases the rate of stabilisation of the landfill materials. Whilst this may reduce the period during which leachate is produced, residual treatment of the leachate will usually still be needed to render it suitable for discharge to a sewerage system or watercourse.

Impermeable liners have been used for a number of years in the Federal Republic of Germany, particularly for special-waste landfills, and in the United States, and more recently to a limited extent in Canada and the United Kingdom. These applications have often been at sites used for domestic waste disposal rather than for hazardous materials. However the United States Environmental Protection Agency is conducting a detailed investigation of the suitability of various soils and membranes for lining both domestic and hazardous waste landfills, and a description of this programme follows.

EPA Investigation Programme on Liner Materials

The Solid and Hazardous Wastes Research Division is evaluating both native soils and various membranes as sanitary landfill liners. Because the base of a sanitary landfill exhibits anaerobic, reducing conditions, the durability of any liner material is in question. Even clay could react with the leachate and cause structural changes in the clay lattice. These changes may cause liner failure by adversely affecting the hydraulic conductivity.

Test cell one at the Boone County field site was constructed by SHWRD using a double liner. The 2 liner materials are a natural silty clay and a 30 mil Hypalon sheet. The clay was back-filled over the Hypalon to a depth of 18 inches. Leachate is collected both above and below the clay liner. The preliminary results indicate that about 6 per cent of the total leachate collected passed through the clay layer. There is no information available, as yet, on the attemuation characteristics of the clay liner. The clay liner used at the site has a hydraulic conductivity of 1.64×10^{-5} cm/sec, some clays have hydraulic conductivities as small as 10^{-8} cm/sec.

Test cell 2 has been constructed using a chlorinated polyethylene liner. No results are available from this site.

An extensive evaulation of liner materials is being conducted under US EPA Research Contract 68-03-0230. Twenty-four lysimeters have been constructed with 12 different materials used as liner materials, including both polymeric membranes and admixed materials as follows:-

Polymeric membranes:

- Polyethylene (PE), 0.25 mm
- Polyvinyl chloride (PVC), 0.51 mm
- Butyl rubber, 1.6 mm
- Chlorosulfonated polyethylene (Hypalon) nylon scrim reinforced, 0.86 mm
- Ethylene propylene rubber (EPDM), 1.3 mm
- Chlorinated polyethylene (CPE), 0.81 mm

Admixed materials

- Paving asphalt concrete, 56 mm
- Hydraulic asphalt concrete, 61 mm
- Soil cement, 114 mm
- Soil asphalt, 102 mm
- Bituminous seal, 76 mm
- Emulsion asphalt on fabric, 76 mm.

Each material is being used in 2 lysimeters. The liners will be removed after one and two years exposure to leachate to determine what changes have occurred in the physical properties of the liner materials. In addition to these 12 materials, there are 34 samples buried in the sand covers above the liners. These materials will also be examined and tested. All of the buried samples have splices, either factory or field, to be evaluated. The lysimeters have only recently been completed, so results from this study will not be available for some time.

The SHWRL is also funding a testing program to evaluate liners subject to leachate from hazardous wastes. Twelve liner materials will be evaluated, 4 synthetics, 4 admixtures, 2 clays, and the contractor can select 2 additional materials. Final selection will be made from the following list:-

Polymeric membranes

Butyl rubber

Chlorinated polyethylene (CPE)

Chlorosulfonated polyethylene (Hypalon)

Ethylene propylene rubber (EPDM)

Neopreme

Polyvinyl chloride (PVC)

3110 (a PVC-type material by DuPont)

Admixed materials

Bentonite clay seal

Emulsified asphalt (Petromat)

Soil cement

Hydraulic asphalt concrete

Compacted fine grained soil

Polymeric bentonite sealant

Acid-resistant concrete

Hot sulfur

One sludge will be strongly acid, one strongly basic, one pesticide, and 3 additional sludges to be chosen by the contractor. The change in physical properties of the liner materials will be determined after one and two years exposure. A total of 144 lysimeters will be built. Also, the contractor will investigate accelerated testing methods for the liner materials.

Other investigations

Other liner studies are currently being conducted in the Federal Republic of Germany (see section III.1.2), and more recently a small research programme has been commenced in the UK. This will comprise laboratory evaluations of selected liner materials, and in-situ field trials of certain of them. The work is being undertaken on behalf of a local waste disposal authority, but no results are yet available.

Reproduced from best available copy.

II.2.2.2. Gas production at landfill sites

Microbial degradation of the putrescible components of domestic waste can give rise to a gas consisting mainly of methane and carbon dioxide, but possibly containing also traces of other gases such as H_2S, NH_3 and N_2. The gas is flammable, with a typical calorific value of 22.4 MJ/m^3, and can be generated over a period of several years. Landfills containing other types of waste do not generally give rise to gases containing methane and carbon dioxide.

Aspects of particular interest for landfill sites are:-

i. Possibility of causing a hazardous situation.

ii. Possibility of collecting and using the gas.

iii. Damage to vegetation and land reclamation schemes.

Hazardous situations

Uncontrolled production of methane gas at landfill sites in the UK has not been a major problem, but 2 examples of potentially hazardous situations have been reported. The first concerns a site in Essex, where a sports field and pavilion were built on land reclaimed from a completed landfill site. Significant amounts of methane were detected in the pavilion and the source was shown to be the area of the former landfill site. At the second site, in Surrey, considerable quantities of gas were generated within a completed landfill site located on chalk which had received mainly domestic and commercial wastes. To prevent a possibly dangerous accumulation of gas, arrangements were provided to collect the gas in a system of pipes and to burn it.

Data on gases produced by decomposition of wastes in landfill sites in the USA is also available, and shows that similar problems have occurred. At least one explosion resulting in death and injury to humans is known to have been caused by methane gas which had accumulated from a landfill. At other sites, the evolution of methane has necessitated extensive collection systems to prevent the gases from reaching buildings or residential areas where potentially hazardous situations could have arisen. Examples of similar situations have occurred in Canada and a recent international discussion meeting was held (13) in recognition of these problems; the proceedings of the meeting will be published in the near future.

Methane recovery and use

Using fermenters operating under controlled conditions, it has been shown that methane can be generated by an in-plant process from the organic material in domestic waste. In the UK, fermentation studies have mainly concentrated on systems characterised by a high liquid to solid ratio; however from the examples described above it appears that when methane has been generated within a landfill site the conditions have been markedly different from those used in the studies. Although the naturally-occurring conditions encountered in some landfill sites can provide a suitable environment for microbial degradation of organic matter, the rate of methane production from solid wastes in a landfill will be much slower than that obtained from a laboratory or pilot-scale digester operating on an agitated slurry. In addition, the yeield of gas per unit weight of organic material would also be smaller under landfill conditions. However, in some instances landfill sites could possibly provide gas for use as a cheap fuel, and some examples of such applications have been reported from the USA. One such example is the Mountain View project in California, in which some 20 wells have been constructed to recover methane-rich gases from a landfill site.

Remedial measures

Methods for stopping the formation of gas in a landfill site once it has commenced do not seem to be available; in such circumstances remedial measures consist usually of collecting the gas and venting it safely to atmosphere, or burning it under controlled conditions. Such measures can necessitate extensive and costly collection systems. Accumulation of gas can be prevented by allowing it to migrate by diffusion from the landfill site; this can be assisted by not over-compacting each layer of waste during the deposition process. Research into gas generation and related problems is currently in hand in some participating countries eg Federal Republic of Germany, UK and USA, but as yet no definite conclusions or recommendation have emerged from these studies.

II.3. Site operation and methods of disposal

II.3.1. Leachate control

II.3.1.1. Compaction of waste

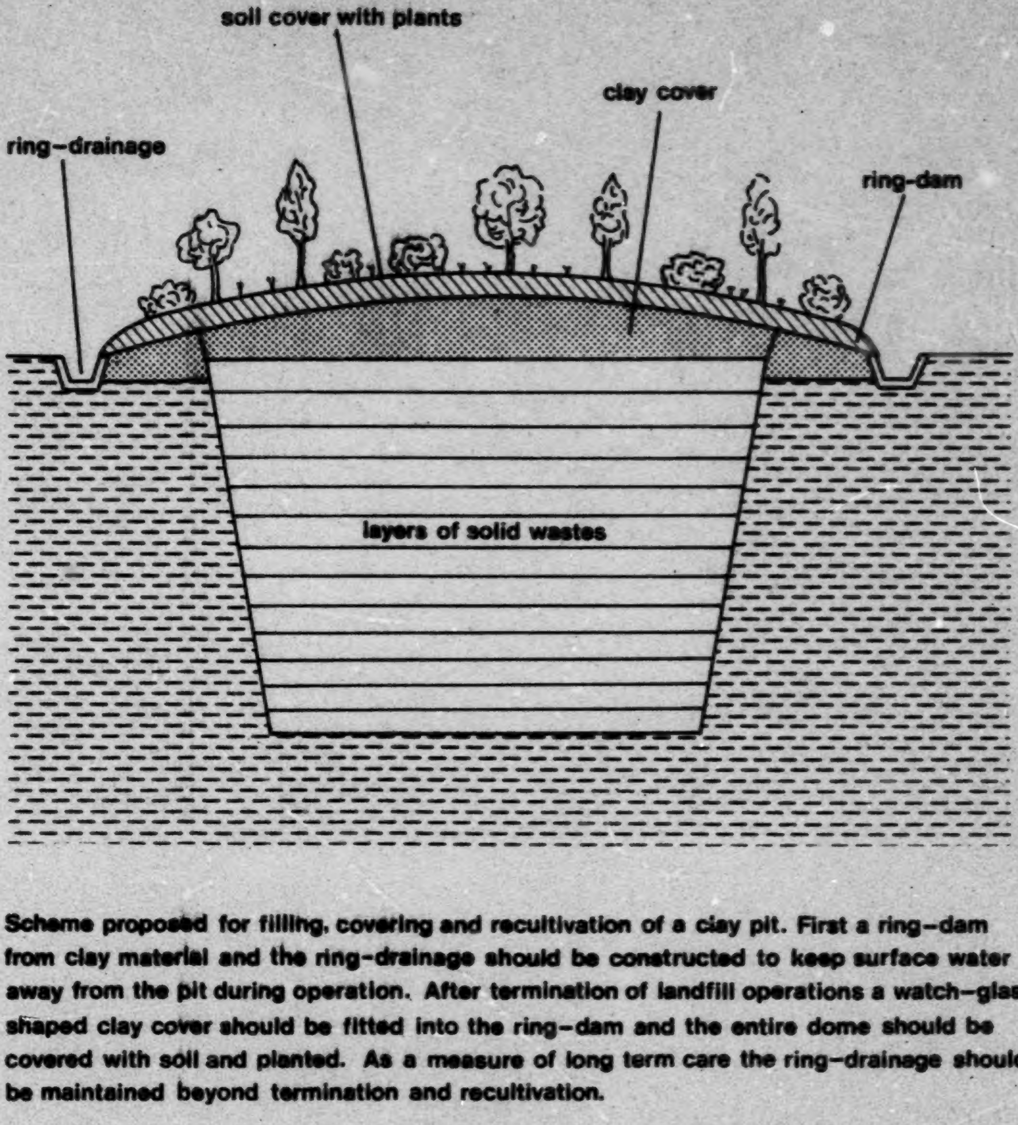
At landfill sites where there is a net annual moisture surplus, a reduction in the volume of leachate generated can be achieved by ensuring that the waste deposited is adequately compacted.

The density of freshly collected municipal waste in the UK is approximately 150 kg/m^3; after normal compaction within a landfill site has occurred the density may be as high as 500 kg/m^3. If special methods of compaction are used for example steel-wheeled compactors, higher densities may be achieved. Investigations carried out in the Netherlands demonstrated that the more waste is compacted, and the greater the total thickness of waste, the smaller the amount of leachate produced per year. The density of waste used in this study was as high as 900 kg/m^3, possibly because it contained a relatively small proportion of paper and a relatively high proportion of moisture and of glass, but also because the compaction was achieved by compactors operating on thin layers of waste. In the UK, simulated landfill experiments have been carried out by the Water Research Centre. Although the main purpose was to study the interaction between selected hazardous wastes and domestic waste during leaching, the design of the experiments also provided useful information on the absorptive capacity of compacted domestic waste. The experiments were conducted on 2 scales: (a) in concrete tanks each 5 m^2 in area and 1.6 m deep, and (b) in PVC pipes (0.07 m^2 in area and 1.6 m deep). The upper surfaces of all units were left uncovered, and the concrete tanks received natural rainfall. In these tanks, 3 selected hazardous wastes, namely a heat-treatment cyanide waste, a metal hydroxide sludge, and an aqueous oil emulsion were studied in admixture with pulverised domestic waste. The cyanide and metal hydroxide wastes were placed in a layer 0.4 m thick sandwiched between 2 layers of pulverised domestic waste, approximately 0.6 m deep above and 0.9 m deep below. The oil emulsion was applied to the surface of pulverised domestic waste over a period of time to give the required loading. At the start of the experiments, no leachate appeared for 7-12 weeks after filling the containers except in the case of the oil units which were saturated by the heavy applications of the emulsion during the first 5 weeks. The initial absorption of water by the domestic waste varied between 0.1 and 0.4 litres per kg of undried waste (moisture content 26%), corresponding to an absorption of rainfall of 50-200 mm per metre depth of waste at a tipped density of 500 kg/m^3. The mean leaching rates during the first year varied considerably. For the cyanide and metal hydroxide units, the rates ranged from 130-190 mm/year giving a mean percolation rate of 16-23% of the annual rainfall. For the oil units, the leaching rates (130-360 mm/year) and percentage percolation (36-40%) were higher, partly due to their initial rapid saturation.

II.3.1.2. Promotion of surface run-off

The quantity of leachate is influenced by the degree of compaction of waste, and the higher the degree of compaction the more readily will incident rainfall run off. Many landfill operations involve the use of an intermediate cover material, which is inert but not necessarily impermeable, for each layer of waste, together with a final top cover. Whilst such measures may not entirely prevent the downward movement of incident rainfall, it may however be possible to design the surface of the landfill so that such rainfall will tend to run off rather than be retained. This process may be assisted by using an impermeable final cover material such as clay. This method has been proposed in various countries, and examples taken from German and Dutch publications are shown in figs 1 and 2.

Fig. 1 (sect. II. 3. 1. 2.)


soil cover with plants
clay cover
ring-drainage
ring-dam
layers of solid wastes

Scheme proposed for filling, covering and recultivation of a clay pit. First a ring-dam from clay material and the ring-drainage should be constructed to keep surface water away from the pit during operation. After termination of landfill operations a watch-glass shaped clay cover should be fitted into the ring-dam and the entire dome should be covered with soil and planted. As a measure of long term care the ring-drainage should be maintained beyond termination and recultivation.

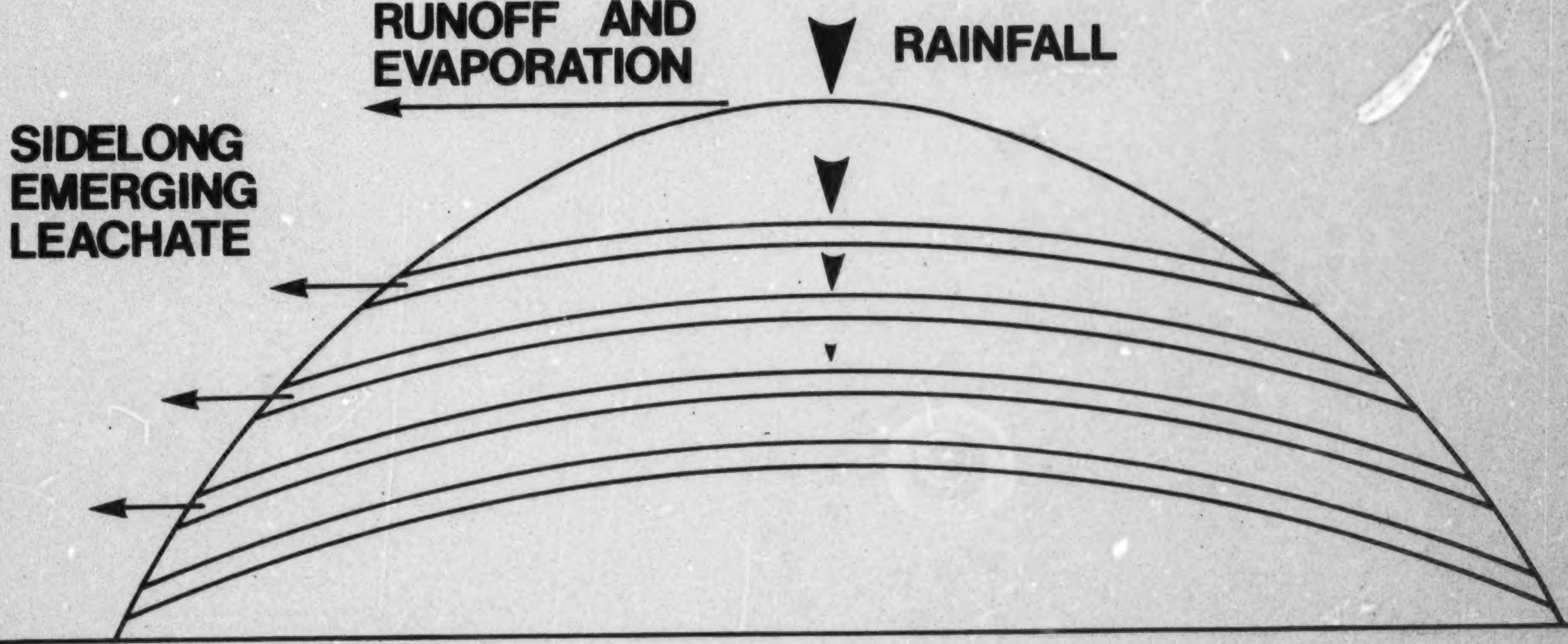

RUNOFF AND EVAPORATION
RAINFALL
SIDELONG EMERGING LEACHATE

Fig. 2 (sect. II.3.1.2.)

SVA Stichting Verwijdering Afvalstoffen

120.142 D

6-10-1975 Em/vK

29b

II.3.2. Methods of Disposal

II.3.2.1. Introduction

Landfill is used in participating countries as a method of disposal for a wide variety of wastes. In physical form, the wastes may include solids, sludges and liquids, and multi-phase systems comprising combinations of these types; additionally, some wastes may be delivered to landfill sites in containers such as metal or plastic drums. Because of their many possible sources, for example domestic, commercial and industrial (including chemical and hazardous materials), wastes also have a wide range of chemical composition.

Given that suitable landfill sites have been selected to accommodate this wide spectrum of wastes, 2 important questions arise:-

1. What will be the effect of depositing a particular waste at a given site.

2. What is the best method for depositing waste of a particular type, ie in what quantities, at what rates and by which techniques should the waste be landfilled.

The first question is capable of being answered in 2 ways: (i) on the basis of experience gained by handling similar wastes at similar sites; this is mainly a comparative technique using historical data, (ii) from data obtained by specific research programmes; this being principally a predictive approach.

The second question has important implications for site operation and management, and it is these aspects that will be specifically considered in this section.

II.3.2.2. Handling methods for particular wastes

Liquid wastes

Large volumes of liquid waste, mainly from industrial sources, are at present disposed of to land in some member countries. At some sites, this has caused problems and presented a risk to water resources, but disposal of liquid wastes to land can under proper supervision provide a satisfactory method of disposal. The principal methods used for disposal of liquid wastes at landfill sites are:-

i. Direct discharge of liquids on to solid wastes.

ii. Discharge of liquids into a system of channels or trenches excavated in stabilised (matured) solid wastes.

iii. Discharge of liquids into a special lagoon.

The first 2 methods depend mainly on the absorptive capacity of the solid wastes to retain the liquids, and thus prevent an excess of liquid from collecting at the base of the landfill. The absorptive capacity of solid wastes will obviously depend on such factors as waste composition and compaction, and the net transmission of rainfall through the site. As an example, for domestic waste in the UK it is typically of the order of 0.15 m^3 of water per tonne of waste, assuming the density of the compacted domestic waste to be about 500 kg/m^3. A further difficulty involved in these methods is that of ensuring that the time allowed for contact between the liquid waste and substrate is adequate to permit maximum absorption to take place; this is especially difficult when liquids are discharged directly on to the substrates, but less so in the case of the channel or trench systems through which liquids flow at a much smaller rate. Trench systems are however more demanding in terms of space requirements, and may only be applicable to particularly large landfill sites where a sufficient area and depth of solid waste is available to allow this technique to be used.

Lagoons are also demanding in terms of space, and may be unsuitable for use at certain sites, either because of the risk of surface spillage or leakage through the base into the underlying strata; they may also have the further disadvantage of introducing an additional risk to the safety of the site operators or users. Compared to the discharge of liquids on to solid wastes, however, they will often have the advantage of greater capacity to receive large volumes of wastes of a given composition. In practice, lagoons have usually been used for reception of liquids of differing compositions; this has frequently resulted in the formation of a complex multi-phase system whose ultimate treatment and disposal can prove extremely difficult. If liquid industrial wastes from different sources are to be accepted for disposal at a landfill site, it is important that appropriate precautions are taken to prevent hazards caused by incompatibility of particular constituents. Examples of such precautions are:-

a. Liquids having a low flash point should not be deposited on a landfill site, other than in exceptional circumstances, and then only under strict supervision. Any other flammable liquids should be disposed of remote from the active working face of the site.

b. Acids, including inorganic and organic acids, and substances contaminated with, or soluble in, or liable to generate acids, may need to be deposited into a bed of neutralising agent (eg granulated lime). Such substances should also not be deposited together with compounds which on reaction would produce toxic, explosive, or inflammable gases, or deposited on hydrogeologically sensitive sites.

c. Strongly alkaline materials (such as caustic alkalis, quicklime or slaked lime) should not be allowed to come into contact, before or after deposition, with either ammonium salts or phenolic compounds.

Sludges

Typical sludges disposed of by landfill include chemically precipitated solids from treatment of process effluents (eg from the metal finishing industry), sludges contaminated with oily materials, and residues from the cleaning-out of various vessels used in chemical processes (eg tank cleanings and cell muds). As in the case of liquid wastes, sludges vary considerably in chemical composition depending on their source, but in addition they also vary in physical composition from thin slurries (solids content only 1-2% by weight) to de-watered residues from mechanical or pressure filters (solids content up to 30-50% by weight). Although such wastes frequently contain substances potentially capable of causing water pollution, their disposal at landfill sites is more likely to be influenced by difficulties involved in handling the materials.

Two possible methods which might be suitable for handling sludges at landfill sites are outlined below; the choice between them will depend on the type and use of the site, and in particular on the nature of other wastes accepted for disposal.

i. Dispersal method

At sites used mainly for solid wastes, such as domestic, commercial and other inert wastes, but which do not receive liquid wastes with which the sludge might react, the sludge should be dispersed fairly evenly throughout the site in admixture with the general landfill materials. To ensure an even distribution, application of the sludge should, as far as is reasonably practicable, be made along the whole length of the working face of the site, and covered with general solid waste soon after deposition.

ii. Segregation method

For sites which receive a wide range of materials, including liquid industrial wastes containing substances capable of reacting with or dissolving the sludge, it is preferable to deposit the sludge on a separate part of the site reserved for that purpose. The specified area within the site can be selected according to operational requirements but should preferably be chosen so that the likelihood of leachate migration or surface run-off from the sludge is acceptably small. To reduce bulk, sludges may be dewatered before disposal; in addition chemical treatment or fixation processes may be useful for certain sludges to minimise the mobility of undesirable constituents at sites where sensitive surface or ground water resources are at risk.

Whichever method of disposal is used for sludges, the following general recommendations should be observed:-

a. Wastes accepted in the form of thin slurries should not be deposited at such a rate or in such quantities that, when the dispersal method is used, the absorptive capacity of admixed solid material is exceeded; such wastes should in any case not be deposited where there is a possibility of the slurries moving directly through channels within or beneath the landfill materials and thereby entering aquifers or surface watercourses.

b. Liquid wastes capable of reacting with or dissolving the sludges should not be disposed of at sites, or areas within sites, where such materials have been deposited.

c. If the site, on completion of landfill operations, is to be redeveloped for agricultural purposes, deposition of sludges containing substances which could adversely affect the growth of crops or grazing animals should be terminated at the maximum depth to which the roots of crops would penetrate, allowance being made for the addition of top soil or other cover material.

For wastes which might in the future have potential for recovery of materials the segregation method would be more suitable; however it is unlikely that such wastes would be landfilled in any case.

Wastes in drums

Although relatively inert solids in drums are acceptable for landfill disposal, drums containing other waste may cause problems such as risk of fire or explosion, and long-term toxicity hazards. The eventual failure of drums and similar containers in the landfill will create voids, and may also cause problems of contact and water pollution hazards.

It is preferable to empty drums, which can then be washed out and possibly re-used, or crushed and then incorporated into the landfill. Emptying of drums should of course only be done under experienced supervision and with due regard to the nature of the contents; for example the UK recommends that limited quantities of used and unrecoverable chlorinated hydrocarbon solvents should be discharged at the foot of the working face of the site not less than 2 metres from the surface and flanks of the landfill (14), and precautions should be taken by the person who empties the drums to prevent hazards due to solvent vapour.

Drums which have contained explosive or inflammable substances should not be re-used or crushed until appropriate precautions have been taken to prevent the risk of fire and explosion.

II.3.2.3. Co-disposal of wastes

There is considerable scope for co-disposal of different wastes to land: much industrial waste is of similar characteristics to domestic waste and can be dealt with using similar controlled tipping techniques. There are also substantial quantities of other industrial wastes, for example spoil, ashes and slags, and sands, which could be used as cover material for more noxious wastes. Provided suitable sites are available, it should be the aim of the responsible authorities to ensure that sites are operated in the optimum manner for all types of waste, thus co-disposal will often represent an important factor in waste management strategies.

Where hydrogeologically safe sites are numerous, the main advantage of co-disposal of wastes of differing characteristics is to facilitate disposal of wastes locally with minimal transport requirement. Where the only sites available are suitable only for inert or relatively inert wastes, possibilities for co-disposal will be more limited.

Co-disposal would not be recommended for wastes with considerable recovery potential, nor for highly noxious wastes which might endanger public safety, but the latter wastes would in any case be landfilled only as a last resort.

When co-disposal is acceptable, the question then arises: which types of waste can be landfilled? Some examples of co-disposal practised in CCMS countries are given below:-

i. Federal Republic of Germany

a. Metal hydroxide sludge is co-disposed of with municipal waste at various sites. At Poppenweiler, Baden-Wurttemberg, for example the sludge is accepted only in dewatered form (solids content about 30% by weight) and at a controlled rate. The method of disposal is to excavate pits in the compacted municipal waste, which are then lined with a layer of loamy soil before being filled with the sludge and covered with a layer of loamy soil and further municipal waste.

b. Acid tar residues from oil reclamation processes are disposed of at several municipal landfills eg Brunswick and Dortmund. The usual method of disposal is to discharge the tars into basins constructed in the area of the working face by heaping up a dam of solid waste so as to make a shallow trough, approximately 5 x 10 m to 5 x 20 m in area and about 1 m in depth. The acid tar is discharged into the trough up to about 50 cm thick and covered immediately with domestic waste to a depth of about 2 m. The acid tar polymerises slowly by reaction with the domestic waste, which is of a generally alkaline nature; the speed of the reaction being enhanced by co-disposal of wastes such as incinerator ash residues. Bulky waste is not necessarily used for this type of co-disposal practice.

c. Various types of industrial liquid wastes and sludges, for example acids, alkalies, lime sludges and oily residues, have been deposited together with municipal waste at the Berlin Wannsee landfill. In this case the liquid wastes and sludges are deposited into large clay-lined lagoons excavated in the municipal waste.

ii. United Kingdom

Some examples of chemical wastes currently being accepted for disposal at some landfill sites operated by local authorities for domestic and commercial wastes are:-

a. Metal hydroxide sludge.

b. Asbestos waste.

c. Solvent-contaminated residues (with high flash point).

d. Soil containing spent oxide from an old gasworks.

e. Dry-cleaning waste.

f. Printing ink sludge.

Wastes which would not normally be regarded as hazardous, and which in principle are suitable for incorporation into domestic waste, include biodegradable materials such as wastes from the manufacture of foods and drinks, and water treatment sludges. Other wastes, which might (depending on quantities and site conditions) be suitable for co-disposal include certain industrial treatment sludges, packaging wastes contaminated with such materials as paints or pesticides, and mixed wastes containing components such as heavy metals particularly if they are present in concentrations not significantly greater than those contributed by normal constituents of domestic waste or soil.

Co-disposal is practised also by private contractors; this technique is particularly useful for the disposal of aqueous industrial wastes using the absorptive capacity of mature domestic waste. At one large and relatively isolated site mutually compatible liquids are mixed in tanks prior to disposal into trenches whilst other aqueous wastes are disposed of in separate areas of the site. Wastes in the latter category at present would include some acids, alkalies, tar liquors and also liquids potentially capable of producing gases or obnoxious odours. Special care is taken in site control of these categories of waste. Solids and thick sludges are generally disposed of at the main working face of the current domestic waste landfill but occasionally special wastes are buried separately.

iii. United States

a. A classification scheme in operation in California for both sites and wastes permits co-disposal under suitable conditions.

b. Several types of industrial wastes are being studied in a programme to evaluate possibilities for co-disposal with municipal waste (15).

II.3.2.4. Special waste disposal facilities

Special-purpose landfill sites for the disposal of chemical and hazardous wastes are being developed in some participating countries.

i. Federal Republic of Germany

a. Schwabach, Bavaria

The special waste disposal facility at Schwabach, Bavaria was the first of its kind in operation in the Federal Republic. Its technical facilities (incineration plant, detoxification plant, neutralization tanks, decantation, emulsion separator, sludge squeezer) will not be described here, instead the following description concentrates on its operation as an example of a special waste landfill.

The facility is located on a gentle hill adjacent to a residential area of the city of Schwabach. This situation turned out to be disadvantageous because of fumes, odours and noise generated by the operation. The pit is 20 to 30 m deep and has a depositional area of 70,000 m^2 and a volume of 500,000 m^3. A paved service road runs around the rim with a concrete ditch, which helps to keep surface waters away from the pit. The former brick clay pit was excavated from a series of Pleistocene river terrace materials and Triassic sediments, eg Keuper marls and sandstones. An intercalation of red shale encountered at the bottom of the pit was also exploited to a large part, so that no natural protection was left for the groundwater aquifer 20 metres below.

To prepare this pit for landfill operation it was completely lined with an artificial sealing and equipped with an efficient drainage system to collect all leachate and conduct it to the effluent treatment plant on site. For sealing material a double layer of compacted clayey loam was chosen, the total thickness being 0.5 m. The clay has a coefficient of permeability of 10^{-7} cm/sec. On top of this layer a basal drainage system of ceramic pipes was placed, embedded in a thin layer of sand and connected to a leachate control tank. There the effluent, which has a varying pH from acid to alkaline, can first be neutralized before it is pumped batch-wise into the effluent treatment plant.

At the slopes of the pit no drainage system was installed, the clay liner was merely covered with a protective soil layer and seeded with grass. Occasional problems arise from creeping and slumping of this cover. Some doubts remain about the ultimate and long-term safety of this design with regard to the wastes being deposited in the pit. The management of the facility agrees that leachate collection and treatment as well as the general care of the landfill will have to be maintained for many decades to come.

Around the facility 7 control wells were installed to allow for sampling and analysis of the groundwater below the pit at regular intervals. There are no other water wells within a radius of several kilometers.

In principle the facility is designed to accept all special wastes being delivered from industry and commerce. On the basis of special regulations and provisos some kinds of waste are in practice excluded, ie acid tar, while used hardening salts are accepted only to be forwarded to the deep mine disposal facility at Herfa-Neurode. A total of 38,800 tons of waste per year (1974) is deposited in the pit. About 40% of the deliveries can be deposited without prior treatment, ie dewatered inorganic sludges and oil-contaminated earth. Liquids and liquid sludges are not accepted, but solid residues from the pretreatment plants such as dewatered metal hydroxide sludges, slags and ashes are deposited. All wastes are deposited jointly in layers of no more than 0.5 m thickness and are compacted to reduce permeability. Drums are opened, emptied and flattened in order not to produce voids in the deposit. Sludges are spread out in thin layers. The surface of the deposit is always kept smooth and given a gentle inclination towards the inlet of the effluent drain to keep the landfill as dry as possible.

In one section of the pit 2 (formerly 4) lagoons are maintained for intermediate storage of oil sludges which cannot be treated nor deposited at the present time with the present facility. The troughs are enclosed by 2-metre high earthen dams and sealed by a compacted clay layer. Below these troughs a control drainage system was installed, separate from the leachate drainage of the landfill area, to control eventual leakage from these storage ponds. In the long run, however, these lagoons will have to be eliminated to permit the undisturbed continuation of the landfill operation.

b. Gallenbach, Bavaria

The Gallenbach special waste site covers an area of 17 hectares which slopes down about 30 m to the west and at a depth of 10-20 m is underlain by a layer of clay loam 8-18 m thick. On the basis of these favourable hydrogeological conditions, seeping of water into the lower ground water level is prevented. Above the loam there are moraine deposits such as gravel and sand, which were removed to construct the site.

In contrast with conventional landfill sites, here the site had to be prepared by excavation and construction of dams. The soil thus excavated, and otherwise in short supply, is employed to cover the deposited special waste.

The site has a capacity of about 1.4 million m^3; this corresponds to a tipping period of about 15-20 years. Construction is planned in 4 phases, the first of which for a deposition volume of 450,000 m^3, was completed within 9 months (end of 1975), subsequent to the required approval procedures as regards waste specifications.

On the basis of the official authorisation the following special types of waste can be deposited at the site:-

Combustion residues from the incinerators of the GSB (Gesellschaft zur Beseitigung von Sondermull in Bayern).

Soil contaminated with oil.

Hydroxide sludges which have been detoxified, neutralised and de-watered satisfactorily.

Process-specific wastes already pretreated at the collection points of the GSB or delivered direct to the site.

Other solid production waste not disposed of together with domestic waste and capable of deposition in the site without preliminary treatment.

A record must be kept of the waste deliveries, giving the source, volume, type and composition of the waste in each case.

The plant comprises the following installations:-

Operational building with amenity rooms of various types for the personnel.

Laboratory for study of the substances delivered.

Vehicle weigh bridge.

Vehicle and instrument shop.

Control systems (drainage, retaining basins) for holding and treating the surface and seepage water.

There are also 2 earth basins sealed with foil, erected as intermediate stores for sludges containing oil. This sludge is treated and/or burned subsequently in the Ebenhausen plant.

Although the thick loam clay under the site virtually eliminates penetration of surface and seepage water into the deeper groundwater zones, a loam seal at least 40 cm thick was also applied to the bottom of the site and on the inner side of the dams. The seepage water is collected by drainage systems (perforated plastic pipes, diameter 10 cm) in filter gravel packing, and led via seepage water shafts (diameter 100 m) into a main manifold (diameter 25 cm, concrete tubes) to seepage-water basins below the site.

It is planned that each additional layer of special refuse (layer thickness about 6 m) is dried by suitable drainage systems so that a sandwich pattern of drainage systems/layer of special refuse/drainage system is produced. Independently of this the surface water is dealt with in its own system. Both types of water reach a total of 3 retaining basins (tanks) with a capacity of about 10,000 m^3 via sand traps. These tanks are sealed with a 2 mm thick plastic foil (Schlegel panel). The water from each filled tank is monitored and if it is of satisfactory quality it is led into the receiving stream, the Paar, a tributary of the Danube. If the water from the retaining basins is not of satisfactory quality, then either a subsequent treatment in situ, or after transport of the water to the chemical physical treatment plant in Ebenhausen, will be required.

For continuous monitoring of the groundwater, observation wells are installed around the site, from which samples are taken at monthly intervals for analysis as regards various parameters (BOD_5, COD, O_2 content, chloride, sulphate, heavy metals).

ii. United States

In Minnesota, a regional chemical waste landfill is being developed as a collaborative project involving private operation and State/local government ownership. The technological and scientific aspects of the project include:-

a. demonstration of site selection methods;

b. demonstration of appropriate site preparation techniques to prevent groundwater infiltration;

c. demonstration of monitoring and surveillance techniques;

d. evaluation of waste handling and operational procedures;

e. determination of costs;

f. evaluation of social and institutional issues.

No specific site has yet been selected, but suitable precautions will be necessary if the project's objective to demonstrate land disposal of chemical wastes so as to preclude leachate migration and groundwater quality degradation is to be achieved. To this end, the Minnesota PCA has proposed 3 levels of environmental safeguards to manage chemical waste leachate. The primary level of protection will consist of an impermeable synthetic liner (such as hypalon, polyvinyl chloride, or rubber) positioned in the bottom of each disposal cell. This liner will be protected by a layer of permeable washed sand. A network of perforated pipes will be installed above the primary liner to facilitate leachate collection and subsequent treatment. A secondary barrier of compacted colloidal clay will underline the primary liner and serve to further protect the groundwater if the primary liner should fail. The secondary barrier will also be served by a separate leachate collection network. Discharge wells will be installed upgradient and downgradient of the site. These wells will serve as a third level of protection to control leachate plume movement in the very unlikely event that both the primary and secondary leachate containment systems should simultaneously fail to perform.

The performance of the leachate management system and groundwater quality will be monitored at all times. The surveillance program will include suction lysimeters underneath the secondary barrier, core soil samples around the perimeter, and observation wells with continuously recording pH and conductivity probes. Groundwater and soil samples will be collected routinely and subjected to comprehensive laboratory analyses to determine the presence of leachate species. Monitoring will continue after the site is closed to assure long-term environmental protection.

Completed waste burial units will be capped with an impervious liner to minimize further infiltration from precipitation.

Surface runoff will be managed and collected on-site. No runoff will be discharged from the site without receiving quality analysis and wastewater treatment, if necessary. Runoff from uncontaminated or non-disposal areas will be collected in lined depressions. Surface runoff from disposal/treatment areas and leachate effluents from disposal units will be collected in separate lined holding basins. Contaminated effluents will be treated on-site by physical and chemical treatment techniques prior to being discharged to the Blue Lake activated sludge wastewater treatment plant for final treatment.

Wastes from 12 major Standard Industrial Classifications (SIC) are generated in the Minneapolis/St Paul area. Foremost among these industries are electroplating, petroleum refining, manufacture of inorganic chemicals, and tanning. Other industrial wastes such as metals mining wastes which are not immediately available within the area will be imported in sufficient quantities to demonstrate their landfilling potential.

The grantee has completed an intial inventory of waste generated in the service area and will augment this data with additional inventory data to formulate the facility's design engineering plan. The overall process design proposed by the Minnesota PCA emphasizes quality control to assure safe waste handling, treatment, and disposal. Waste receiving techniques, including sample analysis, and storage areas, will assure that non-compatible wastes are segregated throughout the entire waste handling, treatment, and disposal process. Employee health monitoring programs and safety equipment will be provided to assure a safe work environment. For example, chemical fire-fighting equipment will be available to control accidental fires.

For incoming chemical waste, disposal decisions will include consideration of:-

a. chemical form (inorganic or organic);

b. persistence;

c. acute or chronic toxicity;

d. genetic effect;

e. flammability/reactivity.

Several waste preparation and treatment techniques have been proposed including: encapsulation, blending, neutralization, fixation, and liquid-solids separation (such as coagulation and flocculation). These techniques will be further evaluated during the facility design phase of the demonstration program.

III. LANDFILL RESEARCH

III.1. Current research in member countries.

III.1.1. CANADA

Research activities on solid waste are carried out in Canada by a number of Provincial Government agencies, a variety of research institutes and university groups, and a multitude of industries, in addition to the Federal Government.

This section describes land disposal research activities carried out by the Federal Government, and in particular by the Waste Management Branch of the Department of Fisheries and the Environment.

The objectives of the programme are:

i. To obtain technical information needed for the preparation of guidelines and the prediction of the environmental effects of proposed waste disposal schemes.

ii. To develop and demonstrate suitable landfill disposal procedures for both municipal and industrial wastes.

For detailed descriptions of these projects, the papers and progress reports presented at the London and Bonn meetings (16, 17, 18, 19) should be consulted.

The main areas of research are as follows:

1. Site evaluation and environmental impact assessment (see Section II.2.1.3)
2. Leachate migration and contaminant attenuation
3. Leachate control
4. Soil-waste interaction studies
5. Development of standard procedures for sampling and analysis
6. Disposal of special wastes
7. Industrial waste management

1. Site evaluation and environmental impact assessment

The objective of this research is to produce a standard procedure which could be used by authorities responsible for waste disposal to evaluate potential disposal sites and assess their environmental effects. Further details have been given in Section II.2.1.3.(q.v.)

2. Leachate migration and contaminant attenuation

i. A comprehensive programme of groundwater monitoring and soil sampling at five landfill sites in central Canada has been undertaken. The landfill sites vary in size from 6 acres to 78 acres (2.4 to 31.6 hectares) and contain from 6 million to 150 million cubic feet (0.17 to 4.3 million cubic meters) of waste. Several of the landfills have received a large variety of domestic, commercial and liquid industrial wastes. The investigations included detailed hydrogeological studies, analyses of samples of soil, leachate and groundwater and the collection of information on the quantities, composition and method of deposition of the wastes present at each site. The data obtained will be used to determine the magnitude of pollutant loadings to receiving waters and the degree of attenuation afforded by the soil at each site. In addition, a contaminant migration model will be developed in order to predict future migration patterns, both for the sites studied and for other landfills.

The results showed that four of the landfills were found to be situated on non-productive lands (former pits and swamps) near major rivers and any deleterious quality effects are restricted to shallow, local groundwater flow systems and to local surface water courses. Soil attenuation is minimal at these sites and leachate discharges occur to nearby streams. The other larger landfill, selected especially for the collection of data for attenuation studies, is situated in an area where a large, shallow, groundwater flow system can be influenced. Groundwater moves about 3000 feet through surficial sand and gravel before discharging to streams.

ii. Leachate migration and attenuation were studied at the CFB Camp Borden landfill site, which has a relatively simple hydrogeological setting. The landfill is situated approximately 60 miles north of Toronto within a lowland physiographic unit. Most of the area falls within a flat to gently undulating "Camp Borden sand plain." For the most part, this basin was at one time part of a lake floor and its surface sediments are therefore of deltaic and lacustrine origin. These loose granular materials have been, in general, well drained by the entrenchment of the rivers of the area, all of which drain to the north, to Georgian Bay.

Groundwater appears to flow in a northerly direction, and laterally within the surface sands. Thus precipitation infiltrates the landfill in nearly a vertical direction, and any contaminants that are leached from the solid waste migrate with this ground water flow. The site receives approximately 6.7 inches of average annual water surplus, based on six years of record. Actual precipitation in the area is approximately 30 inches.

The results to date show that the thickness of the sand varies from approximately 20 ft to more than 80 ft, with the depth to the water table ranging from approximately 3 ft to 33 ft. below ground surface. Based upon the specific conductance measurements, groundwater contamination has been restricted to the sand hydrostratigraphic unit and contaminants appear to have migrated a distance of approximately 2000 ft from the landfill in the direction of groundwater flow. Contaminants are within the sand hydrostratigraphic unit moving over top of the clay soils within the sand hydrostratigraphic unit, with the main flux of contaminants being about 40 feet below the ground surface. Of particular significance with respect to this project is the uniformity in trends observed in the distribution of specific conductance values. The highest values were found near the landfill and they decreased consistently with distance from the landfill. In addition, in vertical profiles the highest readings were found near the centre of the contaminant plume with consistent decreases with distance above and below the centre of the plume. Thus a well defined and geometrically simple contaminant plume appears to exist at the site. The simplicity and regularity of the plume is strong evidence of a simple hydrogeologic setting. Although this simplicity may not be typical of landfill environments, it does provide an ideal setting for the field study of leachate attenuation processes and the testing of numerical simulations procedures for predicting the migration of contaminants

iii. A study is being carried out on a landfill located in a peat bog type of hydrogeological setting, to determine the sub-surface movement of leachates and the potential for contamination of both the underlying aquifer and surface water.

The landfill under investigation is located in the Greater Vancouver area in British Columbia. The 365 acre site is the point of discharge for municipal, commercial, demolition, and other industrial and hazardous wastes. It is situated within a corner of one of the major peat bogs in the lower mainland area of British Columbia, and is probably a typical landfill environment on deltaic deposits in that region.

Previous theories of leachate movement had assumed a continuous stratigraphy, with surface ditch interception of the total leachate flow. However, the geologic setting, determined from the preliminary evaluation of the geologic data, indicated that there were significant statigraphic highs and lows. This, coupled with the known compressibility of peat resulting from the landfill loading, indicated that interception of all the leachate by surface ditches may not occur. Hence, a thorough understanding of the hydrogeology was required.

Based on the known geology, a detailed drilling program was initiated to provide further borehole information, and to install monitoring wells for static/piezometric ground water level measurement and water quality monitoring.

The monitoring activities on site included ground water sampling and analysis, drainage ditch water sampling and analysis, precipitation recording, and recording of tidal fluctuations of the adjacent Fraser River. Falling head or slug tests were carried out to determine the permeabilities of each hydrostratigraphic unit, including the refuse.

The results of the study are still being interpreted, however, it is evident that there are three distinctive stratigraphic units, namely: the refuse which developed combined precipitation and tidal fluctuation response; the peat which had a piezometric level greater than that in the refuse and which was apparently responsive only to fluctuations of barometric pressure; and the underlying sand aquifer, which again showed tidal response. This information would tend to indicate an upward flow gradient in the peat unit, however, it is thought that the high piezometric levels in the peat are a result of peat consolidation and not of confined flow. Indications are also that the confining clay layer appears to retard leachate migration to the lower aquifer, although this is very much dependent on the substained integrity and continuity of the clay layer. There are indications that the clay layer is interspersed with sandy lenses which appear to be hydraulically connected to the lower aquifer. Some of these lenses may be exposed during the operation of the landfill.

Water quality evaluations indicate that leachate has not contaminated the underlying silty sand aquifer. Most leachate appears to flow towards and collect in the adjacent surface drainage ditches, which discharge directly to the Fraser River, although there is also significant flow away from the fill into unconsolidated peat layers. The unconsolidated peat, with a permeability of 10^{-3} cm/sec, is thought to have significant attenuation capabilities.

3. Leachate control

Another west coast landfill, situated on Vancouver Island north of the Greater Victoria area, is under investigation to determine the feasibility of leachate recirculation, over an extended period of time and under annual excess moisture conditions.

A study program was designed specifically to provide data on the effects of leachate recycle onto an existing major landfill. It will produce information which can be used at other sites as well as information specific to the test site. Information will be obtained in the following areas:

a. quantity of leachate emitted by the fill;

b. rate of fill stabilization;

c. disposal of water by evaporation and evapotranspiration; and,

d. use of the fill as a capacitance during peak flows of leachate.

It is recognised that a considerable amount of work has been done elsewhere on the recycling of leachate which has shown that recycling under controlled conditions can accelerate stabilization of landfills and reduce contaminants in the leachate. It has also been found that heavy metals tend to build up in the leachate. The previous results are sufficiently encouraging to consider a full-scale field test on an active sanitary landfill. The study proposed extends the previous work to full-scale.

The landfill started receiving waste in 1959 and was operated for eleven years by open burning. Since 1970 the site has been operated as a sanitary landfill.

The site is located in a bedrock saddle of igneous rock which forms a containment structure from which the only escape for surface water and leachate is a narrow channel. The landfill now covers about 40 acres, with a maximum waste depth of about 120 ft.

The area receives about 40 inches per year of precipitation, primarily during the winter months, and this results in a leachate flow rate varying between virtually nil and 500,000 imp. gpd with an average flow of about 200,000 imp gpd.

In this study, which is just getting underway, it is proposed to recycle leachate by spray onto the surface of the completed portions of the fill to accomplish the following:

1. dispose of water by evaporation, evapotranspiration and absorption into the fill;
2. achieve treatment of the leachate on and in the fill, and,
3. accelerate stabilization of the fill area.

The study program is designed to establish relationships between spray application rate and retention capacity of the fill, evapotranspiration with selected ground cover, removal of BOD and COD, iron removal, tannin and phenol removal and the fate of heavy metals.

The program will continue over an initial three-year period assuming that equilibrium conditions are approached and that adequately representative data are obtained. The study may continue beyond that if fill equilibrium conditions cannot be established in this time.

The recirculation system and the landfill will be monitored by a variety of techniques which include sampling the leachate discharge, sampling well points within the refuse, measuring fill settlement, and recording climatic data and fill temperatures. The data which will be obtained will be applicable to any landfill at which leachate recycling may be either a feasible additional means of control of leachate discharges or a desirable alternative to treatment of leachate by chemical and biological means.

4. Soil - waste interaction studies

The interaction of various industrial and hazardous wastes with typical central Canadian soils has been investigated using the dispersed soil reactor technique developed at the University of Waterloo. This technique consists of mixing and shaking samples of soil and waste in a sealed column under anaerobic conditions, a sample of the leachate being withdrawn for examination after a given time. The remainder of the leachate from the reactor is then subjected to further contact with the same soil in a series of similar reactors until the interaction of the waste with an 11-metre subsurface soil column has been simulated. Following these sorption experiments, the soil column is then subjected to desorption with water to determine the characteristics of contaminant release. The industrial wastes studied were (i) an alkaline phosphate cleaning solution and (ii) an air scrubber effluent (Stretford liquor) from a basic oxygen steel-making furnace.

Both types of waste contained high concentrations of contaminants. The study showed that dilution was an important mechanism for attenuation of all pollutants in wastes, the following contaminants being attenuated primarily by dilution:

Stretford liquor: thiosulphate, thiocyanide, sodium.

Alkaline cleansing waste: sodium, phosphorus.

Metal ions present in both liquids were primarily attenuated by mechanisms other than dilution. It was concluded that both types of waste could safely be disposed of to land provided that factors such as loading rates and dilution factors were considered.

A further study using a modification of dispersed soil reactor technique to study the behaviour of PCBs in soils has been commenced.

This study is designed to provide some basic information on the behaviour of PCBs in soil under anaerobic conditions. It is known that a variety of PCB materials have been discarded at landfills across the country, and PCBs have been detected in landfill leachates in the parts per billion concentration range. The study is scheduled for completion by August, 1977. Thereafter it is likely that a variety of other hazardous materials will be investigated in a similar fashion. The wastes of most concern at this time appear to be arsenic, mercury, phenols, and persistent organics.

5. Development of standard procedures for sampling and analysis

i. Recommended procedures for the analysis of landfill leachate were the subject of a joint Canada-USA investigation, and a report detailing the recommendations has been prepared (18). A second joint report, on procedures for sampling and analysis of soil and groundwater has also been prepared (20). Procedures for the design and implementation of a landfill leachate monitoring programme, and for the control of gas migration from landfills, were also discussed but the results are unlikely to be available within the time-scale of the present CCMS study.

ii. A study of the use of a residual oxygen bioassay procedure for the rapid assessment of landfill leachate toxicity to aquatic organisms has been completed (21). The method enables in-situ determinations of the effects of landfill leachate on surface streams to be made.

6. Disposal of special wastes

The co-disposal of a septic tank sludge with municipal waste under landfill conditions is being investigated. The objective is to determine the optimum ratio of septic tank sludge to municipal waste, so as to obtain an improved quality of leachate and more rapid landfill stabilisation. The work is being carried out under varying conditions of moisture addition. It is hoped to publish guidelines for the acceptance and co-disposal of this waste at landfills on completion of the study.

Preliminary results indicate that the addition of the septic tank sludge can reduce the maximum concentrations of many leachate constituents by between 40 and 100%, exceptions being nitrogen and calcium. In addition, it appears that the total masses of contaminants discharged are also reduced. Biological uptake is thought to be the main factor contributing to the reduced concentrations.

It was noted, however, that at the greater infiltration rates (45 inches per year) the peak concentrations are not reduced to the same extent. Therefore, increasing precipitation rates would appear to offset a fraction of these reductions. With only very early results available, it is premature to present a complete analysis at this time.

7. Industrial waste management.

The characteristics, quantities and methods of disposal of the solid and hazardous wastes from 26 different industries in central Canada have been studied. The purpose of these investigations was to establish basic data on the landfill disposal of typical industrial wastes, and to provide information necessary to promite resource recovery and waste exchange possibilities. The groups of industries studied were:

Group I : petroleum refineries, synthetic rubber and fibres, plastics and resins.

Group II : inorganic chemicals, including acids, alkalies, fertilisers, batteries and explosives.

Group III : iron and steel, non-ferrous alloys, metal recovery and metal finishing.

Group IV : tanneries.

Group V : adhesives, inks, photographic processing.

Group VI : pesticides.

Group VII : pharmaceuticals, paints and varnishes.

III. 1.2 FEDERAL REPUBLIC OF GERMANY

Landfill research in the Federal Republic of Germany has involved several agencies, including projects funded by universities, science foundations, industry and trade associations, and municipal, State and Federal sources. The Federal Environmental Agency in Berlin co-ordinates some of the relevant environmental research funded by the Federal Government, especially by the Ministry of the Interior.

The main research areas are as follows:

Long-term effects of landfills
Landfill leachate and leachate treatment
Attenuation of pollutants in soils and groundwater
Leaching behaviour of special types of waste
Liner studies
Landfill gas generation and control
Influence of rotting processes on leachate and gas production
Co-disposal of domestic waste and sewage sludge
Recultivation of landfill sites

Within these main areas a considerable number of investigations has been commenced, though not all will be complete within the time-scale of the present CCMS study. Descriptions and progress reports of certain projects were given at the London and Bonn meetings (22, 23, 24, 25), and outlines of some particular investigations are summarised below.

1. Effects of leachate on groundwater

A series of studies with regard to leachate - groundwater quality relationships was carried out at a number of landfill sites all over the Federal Republic of Germany. Field studies were in part accompanied with or supplemented by lysimeter studies under laboratory conditions, and/or by experimental landfill studies designed in varying scales and for different purposes. They were operated with different waste and also soil materials, aiming to determine such processes as interactions taking place within the refuse bed or simple leaching behaviour of certain components, mixtures or specific waste materials, or to determine the attenuation of pollutants by the underlying soil bed. Others aimed at comparative investigation of refuse prepared or degraded in different ways (milled, aerobic, anaerobic etc).

The sites investigated contained a variety of waste types including municipal waste, and liquid and solid industrial wastes. As an example, landfill research at the Berlin tip (Wannsee) focussed on gas measurements and the monitoring of groundwater conditions below the large dump where co-disposal of residential, commercial and industrial wastes, including many kinds of special wastes and liquids, is practised. Hazardous wastes were deposited in separate cells for segregation and study. A special report was presented at the London Meeting, October 1975 (24). Preliminary results only, with respect to waste oil, were encouraging.

2. Landfill leachate and leachate treatment

i. A summary of the results of research activities on leachate from municipal waste landfills and on treatment of such leachates, which are grossly contaminated by organic compounds (fatty acids etc), was published at a seminar at Iserlohn in 1974 (26, 27). Some of this research is still continuing, although the interest is gradually shifting from gross contamination of leachate to minor but more critical contaminants such as heavy metals and chlorinated organics.

ii. In a recently completed project, entitled "Determination of concentration of organic and inorganic loads of landfill leachate and their biochemical degradability" (Ermittlung der Konzentration organischer Inhaltsstoffe von Sickerwasser), conducted by the Institut fur Stadtbauwesen of the University of Braunschweig, the quantity and composition of leachate from fifteen landfills of different age, types of waste and mode of operation were studied. All tips were located either on impermeable soils or were lined at the base so that leachate was collected before it passed into the sub-stratum. In this research, the following determinations were made twice a month:

pH, electrical conductivity, dry weight;

BOD_5, COD, TOC (original and upon filtration);

Cl, NH_4-N, NO_3-N, NO_2-N, PO_4-P, total P, CO_3, HCO_3, SO_4;

As, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Na, Ni, Pb, Sr.

With samples having a BOD_5 in excess of 500 mg per litre at least one aerated experiment with sewage sludge was made to verify that the leachate can be treated biologically. During the two-year period of investigation no leachate was encountered that contained inhibiting substances in such a concentration that biological digestion failed. The final report is expected early in 1977.

iii. The Institute fur Stadbauwesen of the University of Braunschweig has started at nine selected landfill sites a follow-up study entitled "Investigations of variation of the quantity and composition of leachate in dependence of landfill age" (Untersuchungen uber die Veranderung der Menge und Zusammensetzung von Sickerwassern aus Mulldeponien in Abhangigkeit vom Deponiealter). First results indicate that the leaching rate is higher with lower compaction (eg bulldozer) than after high compaction (eg steel-wheeled compactor) and that the rate also decreases with increasing thickness of the waste deposit. At a young landfill site with only 2 m of deposit the leachate quantity practically equalled the precipitation rate.

The same institution is also investigating the treatment of landfill leachate in aerated and non-aerated ponds at the landfill site Lingen, Lower-Saxony. Results are not yet available.

3. Attenuation of pollutants in soils and groundwater

i. Attempts to determine the attenuation capacity of soils with regard to contaminants in leachate have been made at various occasions. Two recent publications may be cited, a study on attenuation of heavy metals in landfill leachate (28) and another one that was carried out with particular regard to sewage sludge disposal in exploited peat bogs (29). The latter publication reviews and discusses in detail the knowledge on attenuation processes and concludes that a quantification of attenuation properties of soils is not possible but that the risk of groundwater contamination by landfill leachate is basically predictable. One approach would be a calculation on the basis of the cation exchange capacity and the thickness of the soil below a tip.

ii. The Institute of Ecological Chemistry in Munich investigated the fate of selected synthetic organic compounds in the zone of influence of five controlled refuse tips in the Netherlands (30). Extractions made both from surface soil samples and from water samples were analysed by gas chromatography - mass spectroscopy. The water samples were collected from the unsaturated soil zone by means of collection vessels installed in dug pits in an area between the edge of the tips and a distance of up to 300 m from the dumps. The vessels were made from stainless steel cylinders, 10 cms in diameter, 20 cms high, closed at the base but perforated on top, and inserted into the pits with their bases 50 cms above the water table. The pits were filled with sand up to just above the top of the vessels, the remainder with clay up to the soil surface. Also the surface of the site was covered with a clay drape, an 'umbrella' of a radius of 0.5m, to shelter the collection vessel against direct infiltration of rainwater through the top soil. Upon inspection some of the vessels did not yield any water while others contained highly polluted water thought to be landfill leachate.

Amongst the components of synthetic organic origin were primarily phthalates, PCBs and hexachlorobutadiene. Phthalates are commonly used as plasticizers in plastics, resins and paints and their presence was attributed to the nearby landfill sites. Additional synthetic compounds identified were tri- and tetrachloroethylene, dichloronitrobenzene, pentachlorophenol, and dichlorobenzonitril. In the water samples concentrations of all compounds was in the ppb-range, for example di-ethyl phthalate at 4.1 ppb and di-iso butyl phthalate 0.1 ppb.

4. Leaching behaviour of special wastes

Several investigations are being conducted at present with regard to landfill behaviour of selected special wastes when deposited as such or after pretreatment, or when co-disposed of with domestic waste.

i. Co-disposal of domestic and industrial wastes

The Siedlungsverband Ruhrkohlenbezirk (SVR), an organisation responsible for much of the waste management duties in the Central Ruhr district, initiated in 1970 one of the most interesting projects with regard to hazardous wastes. A total of twenty experimental landfills of 25 x 25 m area and 10m depth were constructed, contained by earthen dams, lined with plastic liners and equipped with drainage systems for the collection of leachates from the individual cells. The cells were charged, layer by layer, with different types of wastes, varying from one cell to another, usually starting at the bottom with a layer of 2m of household waste though in two of the cells incinerator slag was used instead. To allow for comparison, two of the experimental landfills were charged with household wastes only. In the remaining eighteen the following wastes were deposited: plastics mixed into household refuse, polyethylene and polypropylene wastes, PVC-sludges, mixed industrial sludges, sewage sludges, fatty acid residues, resins, tar residues and tar sludge, acid tar, solid and liquid and sludge containing chlorinated hydrocarbons, electroplating sludge, As-Pb- precipitation sludge, furnace linings, aluminium residues, tin wastes, sodium chloride, salt slags from aluminium melting, used contacts, and contact sludge.

The leachates collected regularly over the past five years were analysed for total solids, permanganate demand, chloride, ammonia, sulphate, total Fe, BOD_5, COD, and phenol, whilst the quantitative determination of major cations and heavy metals is pending. The generated data are stored electronically for later convenient interpretation. Results from this set of experiments, which will be continued till 1980, have not yet been published, but a preliminary report entitled "Experience with Joint Deposition of Residential and Industrial Waste with Experiments carried out in the Ruhr District" was presented at the pilot study group meeting in London, October 1975 (22).

Reproduced from best available copy.

ii. Electroplating sludge

Two manufacturers at Giengen, Baden-Wurttemberg, deposit their mechanically dewatered sludges from surface pre-treatment, electroplating and lacquering in a loam pit.

At this landfill the leaching behaviour of the sludge dumps was studied (31). It could be shown that the leachate from this dump did not assume toxic concentration of any of the respective elements contained in the sludge over a five year period of observation (1968 to 1973).

Apparently the sludge had uniquely good properties for landfill disposal due to the fact that the effluents of the two manufacturers are high in phosphate as well as paint residues. When phosphate is - after proper detoxification of the effluents - precipitated with calcium, excess metals are co-precipitated from solution, while the paint residues, like a glue, improve the dewatering and deposition characteristics of the mixed sludge.

In 1974 the Forschungsinstitut fur Edelmetalle und Metallchemie, Schwabisch Gmund, began an investigation of the landfill disposal or recycling of effluent treatment sludges from metal finishing processes. The study deals with the electroplating wastes of an industrial area in the State of Wurttemberg. The following parameters are evaluated on a statistical basis: total amount of sludge per district and month, water content, total content and mean percentages of copper, chromium, nickel, iron, zinc, phosphate and mineral oil. A total of 230 samples were analysed thus far, covering 90 per cent of all metal finishing shops in 12 governmental districts. The samples were also subjected to leaching tests with distilled water and solutions of different composition including landfill leachate.

iii. Metalliferous precipitation sludges

The Duisburger Kupferhutte (DK), which was visited by the pilot study group following the meeting in Bonn, May 1976, extracts valuable metals from sulphide roasting residues and metallurgical waste materials. The extraction processes themselves generate residues in the form of precipitation sludges that contain less desirable metals like iron and arsenic as well as residual quantities of copper, lead, zinc, etc. In these metalliferous sludges arsenic is precipitated as ferric arsenate (scorodite, $Fe^{III}AsO_4\ 2H_2O$), lead as lead sulphate (anglesite) and iron as ferric hydroxide or basic iron sulphate. Another major constituent is gypsum. These metalliferous residues are, for the time being, disposed of at a special-waste landfill near Breitscheid, a clay pit considered as hydrologically safe.

Experimental approaches made thus far have included leaching tests in the laboratory, experimental landfill in mono-component tips, and experimental co-disposal by tipping with domestic waste. The mono-component test fields are located at the DK while co-disposal is investigated at the SVR test fields (see i.).

The aim of the investigations is to establish the chemical stability or leachability respectively of the precipitates under conditions of open-air storage or landfill. Materials being investigated are a scorodite-bearing sludge, an anglesite-bearing sludge, an iron-gypsum sludge containing minor amounts of Cu, Zn, Co, Pb, As, etc, but also a fine-grained raw material eg roasted pyrite, the leachability of which is of interest, since large stock piles are stored in the open for considerable periods of time. Prior to deposition the sludges were partially dewatered.

iv. Spent foundry sands

The Institut fur gewerbliche Wasserwirtschaft und Luft-reinhaltung in Cologne investigates the leaching behaviour of all commonly employed types of spent foundry sands. A first report on experiments with laboratory lysimeters has been published (32).

Although spent foundry sands are mostly quartz sands with minor contributions from the original binding agents or their respective residues of high temperature treatment, the eluates of lysimeter experiments with rain water have properties which do not allow for classification of these wastes as inert. The contamination of the eluates is more varied than the types of binding agents being used. Almost all investigated parameters indicate however, lower concentrations of contaminants in the eluates than commonly encountered in leachates from domestic waste tips. Some of the eluates exhibit extreme pH values, either alkaline (maximum pH of 12.5 determined) or acid (minimum pH of 1.3). It is thus recommended possibly to neutralize acid sands prior to disposal, provided they do not contain phenols. Co-disposal with residential waste is recommended for all types of sands, but landfill of foundry sands alone is not recommended and disposal in water protection zones should be precluded with regard to phenols, formaldehyde and other organic contaminants frequently encountered in eluates from fresh as well as spent foundry sands. Bentonite-containing foundry sands could probably be utilized as landfill liner material because of their good compaction properties, their content of expanding clay minerals and resulting low permeability.

Experiments with field lysimeters continue and publication of the final report is due in spring 1977.

v. Consolidation products from oily sludges

Several different chemical methods have been proposed to consolidate industrial sludges to make them more easy to handle and more resistent to leaching under landfill conditions. Several of these methods are being experimentally applied to oily wastes, particularly to acid tar and sludges from settling tanks of filling stations etc. The products from the consolidation processes are being tested in experimental landfills constructed at the Special Waste Disposal Facility at Schwabach, Bavaria. The aim of this project is to establish means to reduce emissions to air and water from oily sludges (but not waste oil) when they have to be disposed of by landfill, jointly with residential wastes or as such.

The 20 test fields each measure 5 x 10 m in area and are 1 m deep, lined with PE-foil and equipped with individual leachate drainage devices. One series of these cells will be charged with different consolidation products only, another series with consolidated sludges, sandwiched between two layers of domestic waste and covered up with a veneer of sand. One cell will be filled with domestic waste only, for comparison of leachate quality and quantity.

The experiments commenced in October 1976 and will continue through two complete seasonal cycles. The outdoor experiments will be supplemented by bench-scale leaching tests in the laboratory. Initial results are expected in 1977.

5. Liner studies

Although use of liners of various materials, both natural and synthetic, for preparation of landfill sites is no longer uncommon in the Federal Republic of Germany, studies on applicability and dependability of liners as such have only recently been commenced and no results are available yet. The same is true for the question of leachate drainage systems which is closely linked to lining. A study entitled "Sealing of the underground of landfills by means of silica compounds" (Abdichtung des Untergrundes von Mulldeponien mit Hilfe von Kieselsaureverbindungen) has been completed at the Institut fur Wasserbau of the Technical University of Braunschweig, but the final report was not obtained in time to be included into this account.

The Siedlungsverband Ruhrkohlenbezirk (SVR) commenced in December 1976 a four-year investigation of the behaviour and characteristics of ten different liner materials under realistic landfill conditions in a test field of 20 x 40 m at a controlled tip at Geldern, Northrhine-Westphalia. The tip will be operated for residential waste. Four groups of liner materials will be studied:

i. mineral material (clay, mining spoil mixed with a cementing agent);

ii. bitumen, tar;

iii. bituminous sheets welded together;

iv. foils of plastomers.

The aims are to evaluate the resistance of different materials, to make recommendations as to the application of liner materials, and to compare costs and give broad cost estimates.

6. Compaction of waste

The Ingenieur-Buro fur Gesundheitstechnik, Mannheim, is conducting a study from December 1976 until March 1979, entitled "Determination of the density of deposited municipal wastes in landfills" (Ermittlung der Lagerungsdichte von kommunalen Abfällen in Deponien). At eight different sites, where all incoming wastes are weighed, the density within the compacted deposits will be determined by aerial photogrammetry. The sites were selected so that the influence of different techniques of deposition and different types of compactors can be compared. Also settling rates within the waste deposits will be measured.

7. Landfill gas generation and control

The Institut fur Siedlungswasserbau of the University of Stuttgart started a three years study on "Gas control of waste deposits" (Entgasung von Abfallablagerungen) based on previous investigations into this subject in the FRG and USA. The following questions will be studied:

i. How is the gas generated and by what principal factors is it influenced?

ii. How does the gas move and disperse itself through the waste deposit?

iii. What kinds of degassing facilities are practicable and promising?

Experiments and measurements will be carried out both in the laboratory and in the field. Three approaches to degassing will be tested:

1. Insertion of vertical pipes from the top through the final cover of the landfill site and degassing by suction pumps.

2. Emplacement of horizontal perforated tubing into the uppermost layer of waste before application of the final cover, connection to the surface via shafts and choice of ventilation by blower.

3. Degassing through vertical drainage shafts and choice of ventilation by blowers.

In addition biofiltration methods will be developed to deodorize the landfill gas.

8. Co-disposal of domestic waste and sewage sludge

The Amtliche Forschungs - und Materialprufungsanstalt fur das Bauwesen of the University of Stuttgart started, in December 1976, a one-year study on the question of mechanical stability of mounds of solid waste and sewage sludge in relation to the ratio and the method of deposition. The project aims at development of mathematical formulae and tables for engineering needs.

III. 1.3 FRANCE

A research programme consisting of three main aspects has been commenced:

1. Survey of existing sites
2. Disposal of industrial waste
3. Controlled landfill site

1. Survey of existing sites

Surveys of existing tips are now being carried out in many French departments. Inspection of each site enables an information card to be drawn up showing its precise location, the nature of the waste dumped, the name of the proprietor, the risks of seepage and pollution. These are then classified by the degree of danger represented and entered on maps of 1:100000 where they are marked by dots of different colours depending on the danger to the ground water. By analysing pollution flows from uncontrolled dumping this survey should speed up the process of defining the measures to be taken to bring tips into line with the regulations in force and to prevent new tips becoming sources of pollution themselves. By creating a complete system of records these surveys should make it possible for the producer or transporter of waste, wherever he can be identified, to be obliged to alter his practice and transport his waste to an approved centre in the future. At a later stage the task will be to repair the damage done in the past by reclaiming existing tips, at least the most dangerous ones. This programme is already under way, particularly in the North of France, where the survey is being made on the basis of aerial photographs, administrative records and cases brought by local authorities and individuals.

Furthermore, to encourage disposal of industrial waste under correct conditions, systematic surveys of tipping sites are undertaken with the aim of identifying possible sites, taking account of hydrological restrictions. This work is accompanied by in-depth research into the acceptability to the surrounding population of sites considered suitable.

2. Disposal of industrial waste

A programme of basic research is proceeding side-by-side with the survey. A programme recently established by Minister of the Environment comprises at present ten research projects entrusted to various bodies and in fact constitutes the first stage in the development of a more extensive programme over the next few years. The projects involved are listed in Table 1, but they can be summarised briefly as follows:

a. Five of the projects involve the analysis of existing tips containing specifically the following wastes:

   i. acid tars; surface treatment baths; solvents and paints; organic waste from the agricultural and food industries (study no 3)

   ii. fine tailings (study no 4)

   iii. surface treatment sludges (study no 5)

   iv. cyanide waste (study no 7)

   v. wastes from the titanium industry (study no 9)

These projects are intended to determine the behaviour of various types of industrial waste and to provide some understanding of the nature of the different phenomena which may occur in or near a tip. In each case, historical studies of the sites involved are planned, as well as a programme of boring, removal of samples and analysis.

b. The five remaining projects are intended to supply the answers to specific problems relating to the disposal of industrial wastes:

vi. study of the toxicity of leach products (study no 6)

vii. theoretical study of the water balance of a tip (study no 1)

viii. preparation of a leaching test to simulate the behaviour of sludge (study no 2)

ix. investigation of a process to prevent the dissemination of heavy metals (study no 8)

x. study of the integration of tipping into a regional treatment system (study no 10)

The problems of preliminary conditioning of wastes are also taken into account and hardening processes for sludges in particular have already formed the object of various tests. These tests have been full scale, on the treatment of sludges resulting from the purification of effluents from a surface treatment plant but detailed laboratory studies are now in progress with the sime of determining the condition and limits of application of these processes.

3. Controlled landfill site

It has been decided to set up a controlled landfill site to deal with the problems of disposal of industrial waste from the Rouen-Elboeuf urban area. The project makes use of the storage capacity made available by the working of a huge sand and gravel quarry covering an area of 83 hectares. Storage of the waste will thus proceed at the same rate as the use of the quarry, in pits of a volume of 600,000m^3 each. The total volume of the pits planned will be around ten million m^3. Since the base of the tip consists of highly permeable fissured chalk it has been decided to seal each pit with a flexible film of vulcanised elastomers or similar (eg Butyl) which will cover the sides and base of the pit. The film will be mechanically protected to prevent tearing or piercing by machinery (lorries, earth rollers, etc). This protection will consist on the one hand of a layer of sand 20 cm thick after compaction and on the other of a layer of compacted gravel 40 cm thick. The film covering the sides will be protected either by prefabricated slabs or by shotcrete. A bituminous product will seal the joints between the slabs to prevent the entry of water between the slabs and the waterproofing. The site will be used in several phases, each phase involving filling of one pit while afforestation or redevelopment of the pit previously filled is taking place. The waste will be deposited in compacted layers of 2.50m thickness, and 20 to 50 cm of earth or inert waste (eg slag) will be placed between each layer. Finally a thin polyethylene film will close the pit in such a way as to prevent the seepage of rain water through the stored refuse. This protection will be covered by a layer of topsoil which will be planted.

The percolating water retained by the waterproofing should be removed by drainage. The drainage system will be located in the layer of sand in the base of the pit. The drainage water so collected will be removed and directed into a treatment plant before being returned into the Seine.

TABLE 1 : Landfill Research Projects

Study No	Purpose	Summary of research and work programme	(1) Contractin body and scientific officer (2) Duration
1	Study of the development of water and its interaction with the wastes in a tip accepting homogeneous industrial refuse.	- Construction of a physical and hydraulic model of tip composed of alternate layers of waste (sludge and fill) on a substratum - Theoretical modelling and measurement of characteristic parameters of waste - Full scale monitoring of tip, or laboratory simulation.	(1) IRH Mr Colin (2) 24 months
2	Forecasting of chemical stability of dumped industrial residual sludges by means of accelerated leaching tests. Application to sludges containing metallic derivatives.	- Completion of a reliable leaching test, simple to use and applicable to a wide range of wastes, enabling the stability of the sludges to be evaluated. The research will bear on eight types of sludge and the results will apply to about twenty more.	(1) IRH Mr Colin (2) 24 months
3	Methodological study of the interaction between industrial refuse tips and the environment. Practical application to 4 types of dump in Artois-Picardie.	- Identification of refuse - Study of characteristics of each site - Study of soil contamination - Supervision of water pollution - Research into methods of decontamination.	(1) CERCHAR Mr Busso (2) 18 months
4	Study of the hydrodynamic behaviour and chemical evolution of dumped fine tailings (effects on the environment)	The aim is to define methods of piling wastes, adapted to flotation sludges - hydrogeological and hydrodynamic studies of tips - hydrochemical study.	(1) BRGM Mr Goni (2) 24 months
5	Study of the SODETAL (Laimont) tip (surface treatment sludges)	- Compilation of analyses - Creation of nine test probes - Analysis of groundwater and sub-stratum clays.	(1) BRGM Mr Hentige (2) 12 months

TABLE 1 (contd.)

Study No	Purpose	Summary of research and work programme	(1) Contracting body and scientific officer (2) Duration
6	Development of monitoring procedures for the evolution and effects of deposits of solid refuse.	- Bringing properly controlled populations of micro-organisms into contact with irrigation water from a certain number of industrial wastes within a specially adapted reactor.	(1) IRCHA Mr Brouzes (2) 24 months
7	Study of the stabilisation conditions of cyanide residues on the basis of the Laneuveville tip near Nancy	- Study by means of boring, sampling and analysis of the propagation of cyanide residues in the soil and subsoil as well as in surface and ground water.	(1) Ecole Nationale Superieure de Geologie Appliquee (Higher National Institute of Applied Geology) Mr Demassieux (2) 12 months
8	Study of a process to prevent dissemination of heavy metals in the subsoil of industrial tips.	- Laboratory research and experimentation on a retention material, possibly clay containing a complexing agent.	(1) CEA Mr Guizerix (2) 24 months
9	Interaction of wastes from the titanium and electro-chemical industries on the same tip. Propagation, transfer mechanism of certain pollutants and effect on the surroundings.	- Study of documentation on these tips - Programmes of sampling from the tip and underlying soils - Analysis of raw materials used, wastes dumped, cores removed as well as liquids collected in the base of the tip and ground water - Leaching tests - Determination of a water balance.	(1) SGAL Mr Simler (2) 18 months
10	Dumping of industrial wastes: integration of results of analysis relating to dumping into regional analysis of waste disposal	- Synthesis of results of surveys - Regional division by types of refuse - Survey and qualitative - Preparation of a scale of criteria.	(1) U T Compiegne Mr Caignault (2) 24 months

III. 1.4 NETHERLANDS

In this country, the disposal of chemical or industrial wastes to land is only permitted when other methods of handling the waste such as treatment and recycling are not possible. The co-disposal of chemical and municipal wastes is not accepted as a normal procedure, thus only in exceptional circumstances can landfill be regarded as a possible disposal method for industrial wastes. Consequently, landfill research in the Netherlands mainly concerns municipal wastes. The particular areas of research are:

1. The generation and quantity of leachate
2. The composition of leachate
3. The purification of leachate in the soil
4. Standard leachate tests

The first three areas have as their particular objective the study of methods by which these effects can be influenced. The projects are controlled by the Stichting Verwijdering Afvalstoffen (SVA), Amersfoort.

1. Generation and quantity of leachate

The production of leachate is being studied at several disposal sites in the Netherlands, using test fields with a surface area of 100m^2 and fitted with liners and collecting drains for measuring and recording the quantity of leachate. The test fields are filled with municipal waste, which is compacted to varying degrees to investigate the effect of compaction on leachate production. By locating several test fields immediately adjacent to each other, the importance of leachate movement through channels in the tipped waste is also being investigated. In a further study using similar techniques, the moisture content in tipped waste is being investigated by means of tensiometers installed in clay layers which were deposited at different depths within the tip. The aim of this latter experiment is to predict the tendency for leachate production at a given site; it is however necessary to make the assumption that the moisture content of the tipped waste corresponds with that measured by the tensiometers installed in the clay layers.

2. Composition of leachate

i. Sampling and analysis of leachate from the various test fields described above has been periodically undertaken; the leachate being analysed for a range of constituents including total nitrogen, total phosphorus, chloride, sulphate, heavy metals, COD and pH. More recently, a programme to investigate the presence of PCBs has been commenced. From the analytical data, the relation between the chemical and compaction characteristics of the tipped waste and the composition of the leachate is being investigated.

ii. The interaction between municipal and industrial waste with respect to the composition of leachate is being studied both on large-scale test fields and laboratory-scale column experiments. In the large-scale experiments, municipal waste and paint waste consisting largely of packaging material are being studied. The leachate quality is determined by continuous measurement of COD, pH and conductivity, other constituents such as heavy metals being determined as required. A control experiment using only municipal waste is being conducted for comparison of results. The laboratory-scale experiments include leachate tests on columns containing mixed metal hydroxide sludges and municipal wastes.

Preliminary results after one year from the large-scale experiments show no significant differences between the two test fields and only slight differences between these fields and a "pure domestic" test field. From the laboratory-scale experiments, after six months only slight differences exist between the columns containing domestic waste mixed with metal sludges and those containing only domestic waste.

3. Purification of leachate in the soil

The importance of processes such as chemical and microbial degradation, chemical precipitation, and adsorption, in modifying the composition of leachate so as to render it less polluting, is being investigated by laboratory-scale column experiments.

In general it is evident that the degree of contamination of groundwater is less than that calculated on the basis of dilution of the leachate, and it appears that processes in the soil are operating in addition to dilution. Such processes are believed to include adsorption (eg on soil organic matter), chemical precipitation (as insoluble sulphides and/or carbonates), decomposition into volatile components, and by adsorption on bacterial slimes.

4. Standard leachate tests

A programme intended to define and develop a standard leachate test has been commenced in order to investigate the behaviour of the wastes in a landfill with respect to the amount and composition of leachate. In this work, extraction tests using water, leachate or other liquids are being carried out on the laboratory scale.

III. 1.5 NORWAY

A research programme on the problem of leachate generation from landfills is being sponsored by the Norwegian Council of Natural and Scientific Research (NTNF). The main objective of this programme is to investigate the relation between climatic variations and the amount and composition of leachate, but other important correlations will also be investigated, including the age of the landfill, the method of operation and the leachate characteristics. It is hoped that the programme will answer the following questions:

a. What proportion of the total precipitation appears as leachate?

b. Is there any connection between the leachate flow rate and the concentration of polluting material in the leachate?

c. Would a possible difference in the degree of pollution be equalised through low and high hydraulic leachate loads?

d. Is there any connection between the amount of precipitation and the leaching of different chemical substances?

e. Would the disposal of sludges increase the strength of the leachate?

f. Does shredding of waste change the leachate characteristics?

g. Does the method of site operation have any important effect on minimising the degree of pollution?

h. How do the leachate characteristics vary with time?

1. Site investigations

Five landfills, varying in factors such as annual precipitation, method of compaction, and collection of leachate, have been selected for study. The landfills contain mostly municipal wastes and sewage sludge and do not include hazardous materials. The following measurements are included in these investigations:

i. Continuous recording of leachate flow rate.

ii. Continuous sampling of leachate for determination of pH, COD, P, N, Fe, Zn, Cd and E Coli.

iii. Recording of natural precipitation and ambient temperature.

iv. Temperature and moisture content at different depths within the landfills.

v. Inventory of waste delivered to the landfills.

vi. Volumetric measurements of the waste to study the settling characteristics.

vii. Analyses of receiving waters, airborne waste, odours etc in the vicinity of the sites.

The investigations are still in progress and a report is expected during 1977.

2. Laboratory investigations

i. Solid waste sampling

A special technique for sampling shredded municipal waste has been developed by SINTEF (the Foundation of Scientific and Industrial Research), and equipment designed to obtain representative small samples for chemical analysis from bulk quantities of 300-400 kg of waste has been constructed. This equipment, the Sintester, comprises a feed hopper feeding through a distributor to the sample receivers, which are located on a rotating circular table. The distributor consists of a stationary and a rotating circular grate, the effective separation being determined by the particle size distribution of the material to be handled and the speed of rotation (see fig 3). The unit has been used in the laboratory for sampling municipal solid waste, and has also been temporarily installed at a landfill in conjunction with a pilot-scale hammer mill to investigate the composition of the incoming waste.

ii. Column studies of leachate characteristics

Generation of leachate in different types of waste is being studied in columns 0.2m in diameter and 2m in length, having specially designed leachate collection arrangements for collecting separately the leachates generated (a) near the column walls, and (b) by the main bulk of the waste. The wastes being studied at present include:

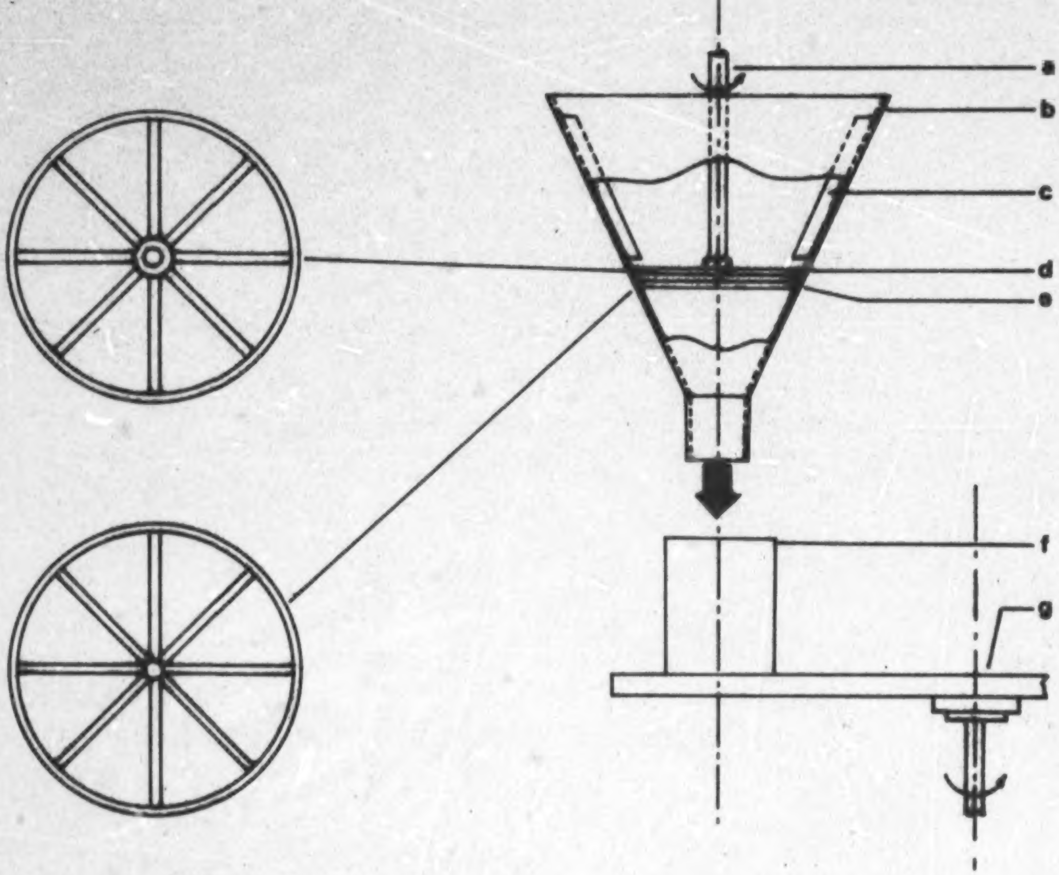
a. aerobically degraded domestic waste (shredded)

b. anaerobically degraded domestic waste (shredded)

c. maturing compost (from household waste)

d. matured compost (from household waste)

In the initial experiments using columns, particular attention has been given to the problem of obtaining reproducible results using several similar columns, so that it would then be possible to study the effect of adding a specified waste (eg a hazardous material) to one or more columns. To obtain reproducible performance, the columns were packed with material obtained by using the Sintester equipment to provide a representative sample of the waste to be studied. The results obtained from two similar columns containing domestic waste and which received the same quantity of water daily are shown in fig 4, and demonstrate both physical and chemical reproducibility of the two columns.



a – shaft
b – mass feed hopper
c – baffle
d – rotating wheel
e – stationary wheel
f – collection container
g – rotating disc

Fig. 3. Illustration of SINTESTER with large distributor (sect. III.1.5)

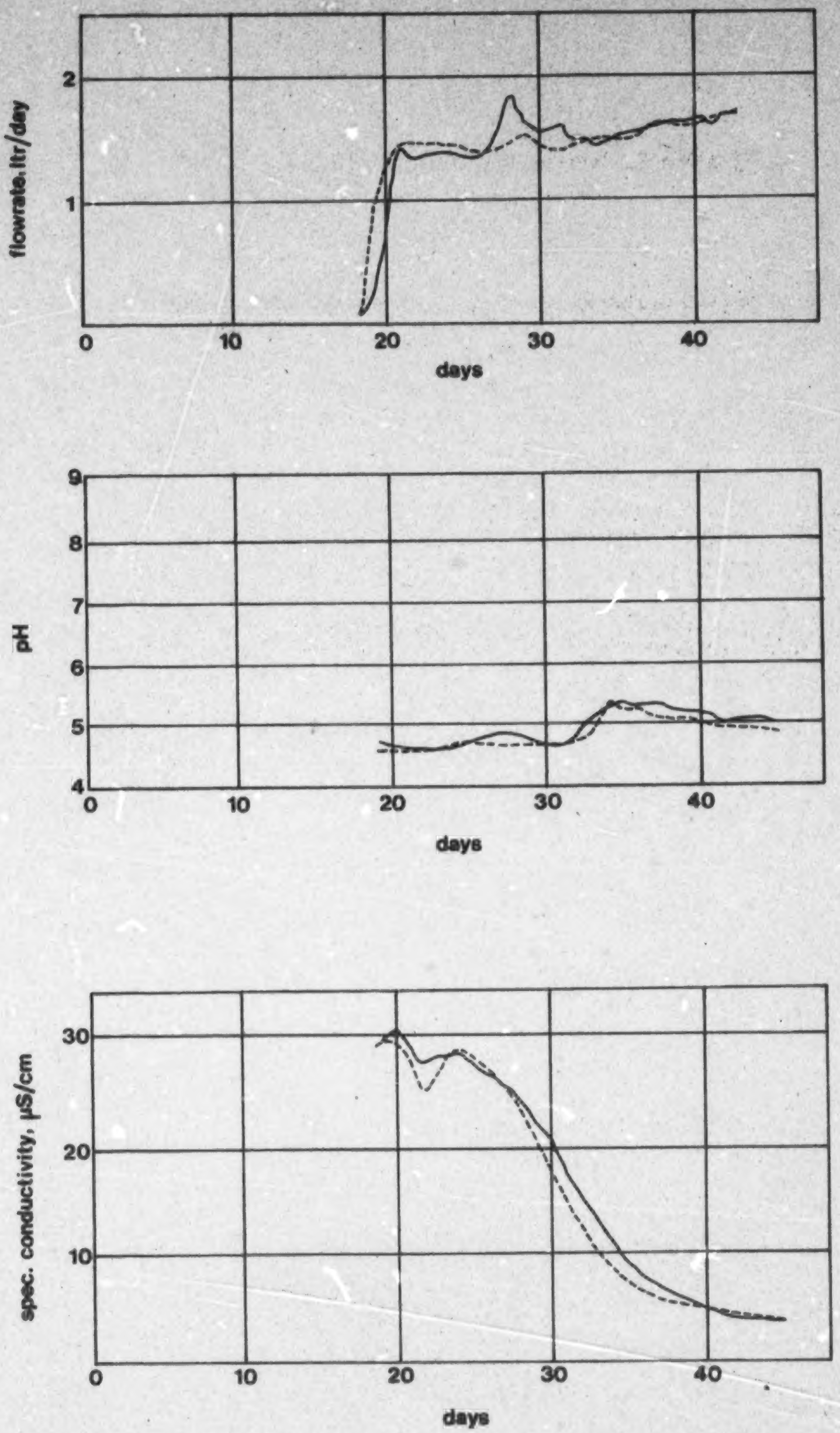


Fig. 4. Variation in leachate flowrate, pH and specific conductivity with time (sect. III.1.5.)

III. 1.6 UNITED KINGDOM

The UK Landfill Research Programme is sponsored by the Department of the Environment, and has the following basic objectives:

i. To ascertain with sufficient assurance by study of an appropriate sample of existing landfill sites, which types of sites are permanently safe and which are not, and if not, the remedial measures that should be instituted.

ii. To establish guidelines for waste disposal authorities so that they can properly discharge their duties of providing suitable sites for receiving industrial wastes, and to establish field techniques which they could use to control and monitor conditions at sites.

iii. To collaborate with local authorities so that staff may become associated with the field work and may thereby prepare themselves for their additional duties.

The present research programme commenced in late 1973 and the final report is expected in Autumn 1977. An interim report on progress (12) was published in March 1976, and additional reports were presented at the London and Bonn meetings (3, 11, 33). The main research areas are:

1. Field investigations at selected landfill sites of different types, to obtain as much information as possible about the influence of the major variables that determine the behaviour and fate of hazardous materials under landfill conditions.

2. Laboratory studies under controlled conditions, to supplement and aid the interpretation of the field investigations. The work includes studies of the chemical and physical behaviour of particular wastes under a range of conditions which simulate those likely to occur in landfill sites.

3. Studies of the movement of pollutants through various types of geological strata, to examine the mechanisms of removal, attenuation or delay which occur in the unsaturated and saturated zones beneath landfill sites.

4. Mathematical modelling of the behaviour of hazardous materials within the landfill interior, and in the underlying saturated and unsaturated zones.

The work is being carried out by two research teams, one from the Water Research Centre, and the second a combined team involving staff of the Institute of Geological Sciences and the Harwell Laboratory, UKAEA.

1. Site investigations

The essential objective of each site investigation was to describe as fully as possible the behaviour and fate of the hazardous wastes. In selecting the sites for investigation, due account was taken of geological and hydrogeological factors together with the composition, quantities and types of wastes present. The classification schemes devised for geological properties and waste categories have been described in previous reports (11, 12) and will not be repeated here.

A total of 20 sites was investigated, the sites being located in different regions of the UK as shown in Table 1. At most of these sites, the procedure for investigation was basically as follows:

i. Collection of available records and other information about the site.

ii. Preliminary site surveys, including pilot boreholes and geophysical surveys as appropriate.

iii. Main borehole construction stage at strategic points within and around the site, with a comprehensive programme of sampling and analysis of core material, liquids and groundwater.

iv. Determinations of groundwater flow, rock properties, borehole geophysical logging etc as required.

v. Continuation of groundwater sampling and analysis to trace the migration of leachate.

At certain sites, a more limited investigation was carried out to establish the fate of particular hazardous wastes; investigations of this type did not usually involve borehole construction or detailed groundwater monitoring.

Detailed reports on each site are being prepared and it is expected that these will be available to supplement the main programme final report. As examples of the type of information being obtained, the following brief descriptions of some of the sites are given.

a. Coatham Stob, Teesside, Cleveland

The site consists of an abandoned quarry excavated in an igneous dyke to a depth of 15-20m below ground level, and has been used for the deposition of liquids and sludges from chromite ore processing. The dyke is of doleritic composition and is intruded into red sandstones of Triassic age; the sandstones having undergone contact metamorphism and fracturing along the margins of the dyke. The undisturbed groundwater gradients dip at a low angle to the east and pass some 5-6m below the base of the quarry. Groundwater flows close to the line of the dyke are unconfined, but at distances greater than 100m confined conditions prevail. Excavation of the dyke rock also removed the surface layer of low-permeability glacial clay and led to the diversion of surface water flows from an area approximately equal in size to the quarry. This additional recharge, added to the water content of the chromite waste itself, maintains a recharge mound 4-5m high beneath the active tipping area. Hydrodynamic dispersion of the leachate laterally and up-gradient in the groundwater zone has occurred. Groundwater flows within the essentially horizontally-bedded sandstones are dominantly intergranular, except near the dyke margins where the extensive baking and fracturing have created a zone of high secondary permeability. A density differential between the fresh leachate and the local groundwater has encouraged vertical flows along the dyke margin to depths of 80-100m below ground level. Away from the zone of fractured sandstones, horizontal flows predominate and a multi-lobate pollution plume confined between lenticular low-permeability layers has formed. Decreasing concentrations of chromium have been detected at distances of up to 250m from the landfill, showing that attenuation has occurred to a slight extent probably by adsorption on clay minerals and precipitation within the interstices of the sandstone. Calculations have shown that, allowing for uncertainties in the observations, approximately 30% of the deposited soluble chromium remains within the aquifer near the landfill, and some 25% within the landfill itself. The remainder is thought to have been retained within the dyke or to have migrated along the dyke in the direction of groundwater flow.

b. Ingham, Suffolk

Mixed industrial, agricultural and chemical wastes were deposited in a worked-out gravel pit overlying Upper Chalk. The groundwater is unconfined and has a low local gradient towards the south-west; an unsaturated zone approximately 20m in depth underlies the base of the landfill. Organic contaminants, measured as total organic carbon (TOC), are rapidly attenuated from beneath the base of the landfill to the water table. The maximum extent of groundwater contamination is confined to the uppermost 5m of the saturated zone in the direction of groundwater movement. Marked attentuation of TOC, phenols and chlorinated solvents was observed within a distance of approximately 100m in the direction of groundwater flow away from the site.

TABLE 1

England

Site	Geology	Wastes Present
Coatham Stob, Teesside, Cleveland	Dolerite dyke removed from Bunter Sandstone	Chromate waste
Ewelme, Oxfordshire	Sand and gravel overlying Chalk	Paint wastes, metal surface treatment wastes
Flitwick, Bedfordshire	Lower Greensand overlying clay	Oily wastes
Haigh Quarry, South Yorkshire	Coal Measures Sandstones	Chemically-treated industrial wastes
Hammerwich, Staffordshire	Poorly consolidated Bunter Sandstone	Organics, heat-treatment cyanide wastes
Hooton, Wirral, Cheshire	Boulder Clay over Triassic Sandstone	Oily wastes and mercury
Ingham, Suffolk	Permeable sand and gravel overlying Chalk	Mixed industrial wastes including phenols
Mitco Site, West Midlands	Etruria Marl overlying Middle Coal Measures	Liquid wastes (especially acids) in a lagoon
Rainham, Essex	Thin clay overlying sands and chalk	Mixed wastes including metals and organics
Shaw, Lancashire	Peat deposits overlying glacial sands and gravels	Mercury (in scrap fluorescent lamp tubes)
Tanfield Lea, County Durham	Clays and silts overlying Coal Measures Sandstone	Zinc-carbon primary cells, containing mercury
Villa Farm, Wolvey, Warwickshire	Sands and clays of variable permeability	Oily and liquid wastes
Wildmoor, Worcestershire	Bunter Sandstone	Metal wastes and oils

Scotland

Site	Geology	Wastes Present
Eastfield Quarry	Coal Measures sandstones and shales	Domestic and oily wastes
Greenoakhill Sand Quarry, Mount Vernon, Lanarkshire	Glacial sand and gravel overlying Coal Measures sandstones and shales	Mixed industrial wastes
Kingskettle, Fife	Glacial deposits overlying sandstones	Residues from coal-gas manufacture
Leoch, Dundee, Tayside	Old Red Sandstone	Smelted dry batteries, containing mercury.

TABLE 1 (Continued)

Wales

Site	Geology	Wastes Present
Brofiskin, Mid-Glamorgan	Fissured Carboniferous Limestone	Organic wastes
Maendy, Mid-Glamorgan	Coal Measures Sandstones	Organic wastes
Tythegston, Mid-Glamorgan	Fissured Carboniferous Limestone	Domestic and industrial wastes including oils

2. Laboratory investigations

These investigations permit a more detailed study of the range of possible interactions between hazardous materials and other wastes than could be achieved by site investigations alone.

A particular objective of these studies is the assessment of possibilities for co-disposal of certain hazardous wastes with domestic waste.

The studies so far commenced have been designed to investigate the overall behaviour of particular hazardous wastes in landfills rather than to examine in detail any specific removal or retention process. The investigations are being carried out on both the laboratory and pilot-plant scales, and some examples follow.

i. Experiments with simulated landfills

Three types of waste, namely a heat-treatment cyanide waste, a metal hydroxide sludge containing mainly nickel and chromium, and an aqueous oil emulsion were used, in admixture with compacted and pulverised domestic waste. The experiments were conducted on two scales: firstly in concrete tanks of $5m^2$ area and 1.6m depth, and secondly in PVC pipes of $0.07m^2$ area and 1.6m depth. For each waste two tanks and two pipes were used; free access of air being permitted to the base of one tank and one pipe to provide partially aerobic operation whilst the remaining pair were sealed at the base to permit anaerobic operation. The tanks were operated in the open and received natural rainfall whilst the pipes were located in the laboratory using artificial irrigation. The volume and composition of the leachate from each unit were determined regularly during the study period (up to 2½ years), after which time the residual contents of the units were re-analysed. Results from the latter examinations are not yet available, but results obtained from the leachate analyses indicate that:

a. In the case of the cyanide waste, the quantity of cyanide leached in 2½ years was less than 3% of that present initially. Thiocyanate in leachate is unlikely to have accounted for more than a further 4%. Concentrations of cyanide attained maximum values of 73 and 270 mg CN^-/litre from the aerobic and anaerobic pipes respectively but decreased when the leaching rate was reduced after 30 weeks. Concentrations in the leachate from the tank experiments, where the leaching rate was lower, did not exceed 7 mg/litre during the same period.

b. In the experiments where metal hydroxide sludge was added, the fractions of nickel and chromium leached were less than 0.2% of the weights initially present in the sludge; for other metals the fractions leached were generally much less than 10%. Median concentrations in leachate from an anaerobic experiment were generally greater than in leachate from the corresponding aerobic experiment, though copper, and to a lesser degree cobalt and zinc, differed.

c. The weight of oil leached that could reasonably be attributed to the addition of oil emulsion was less than 2% of the weight added; concentrations higher than the "background" value of 10 mg/litre being observed only during and immediately after the addition of the emulsion. No concentration in leachate exceeded 300 mg/litre, and most were much lower.

For each type of waste, definite conclusions about the quantities and rates of leaching should be possible when excavation and analysis of the units has been completed. Methods of interpreting the data to enable comparisons to be made between aerobic and anaerobic experiments, and between the tank and pipe experiments, are being developed.

ii. Laboratory studies of particular hazardous wastes

a. Wastes from coal carbonisation processes, such as phenolic lime sludges, have been subjected to a programme of leaching absorption and desorption studies to assess the possibilities for co-disposal in conjunction with domestic waste. Although experimental results have indicated that some absorption of phenol occurs according to an isotherm of the Freundlich type $Y = Kc^a$, the absorption is fully reversible, so that this process could not be relied on to reduce the concentration of phenols in leachate from lime sludges to acceptable values. The presence of domestic waste would however delay the passage of phenols from the landfill surface to the base, thus causing the concentration in leachate to increase more slowly than it would otherwise do. This delay may increase the possibility of biodegradation of phenol by allowing more time for the micro-organisms within the landfill to act.

b. Various types of halogenated organic wastes, such as solvent wastes from dry-cleaning processes, have been examined using similar methods and apparatus to those used in the study of tarry wastes. The purpose of these experiments is to assess the tendency for loss or retention of such compounds from the landfill by such mechanisms as evaporation, volatilisation and absorption, and to determine at what rates and in what quantities these wastes could safely be accepted at domestic waste landfill sites.

3. Studies of movement of pollutants in the unsaturated zone

In large areas of the United Kingdom, there is often an unsaturated zone beneath a landfill. This zone may be several metres thick, and may thus provide an important natural means by which the movement of leachate, and the attenuation of potential contaminants are controlled. Because of the diversity of conditions in the unsaturated zone, three rock types (sand, chalk and gravel) representative of important aquifer strata in the Uk were examined in detail using both laboratory and field-scale techniques.

i. Sand

For the investigations in sand, in which groundwater flow is by intergranular movement, a field-scale lysimeter experiment was required. The experimental site is located at Uffington, Oxfordshire, where four lysimeters in Lower Greensand were constructed; this site was visited by delegates to the experts meeting held in London during October 1975. Each lysimeter consists of a 4 x 4 x 3 - metre block of sand, underlain by impermeable clay and isolated by means of impermeable vertical walls. This method of construction enables bulk samples of sand to be isolated in a relatively undisturbed condition so that pollutants will move under conditions approximating to those encountered beneath real landfill sites; it was thought that it might be unwise to extrapolate results obtained from smaller-scale experiments (such as laboratory columns) in which disturbed sand samples are used. The lysimeters are each fitted with an irrigation system for applying artificial leachates of differing composition, and contain suction probes, tensiometers and neutron probes to monitor the downward movement of leachates and to withdraw samples at various depths for chemical analysis. Probes for taking gas samples from the lysimeters, and thermocouples for measurement of temperature have also been installed.

The composition of the 3 artificial leachates currently being applied are as follows:

a. A solution containing heavy metal ions (typically at concentrations of 100 mg/litre), alkali and alkaline earth metal ions, lower straight-chain carboxylic acids and phenol.

b. A solution containing organic compounds, including phenol, 2, 4-dichlorophenol and aniline, all at a nominal concentration of 100 mg/litre, together with acetate.

c. A solution containing various anions, eg sulphate (at 2500 mg/litre), chloride (2100 mg/litre), nitrate and phosphate both 100 mg/litre), bromide (40 mg/litre), and acetate (100 mg/litre).

Prior to the application of artificial leachates, the lysimeters were irrigated with mains water in order to establish equilibrium flow conditions. The first artificial leachate used was that containing metal ions, which was applied from October 1975. After 130 days operation, the heavy metal ions had not yet reached the uppermost suction probe (depth 0.62m) though the concentrations of the alkali and alkaline earth metal ions had commenced to rise. Cores of sand taken from the top surface of the lysimeter after 54 days showed that the heavy metal ions were being absorbed or precipitated in the upper 10 cm of sand; after 120 days irrigation even the most mobile heavy metals had penetrated only to a depth of 20 cm. In the leachate (b) containing organic compounds it was originally intended to include trichloroethylene, 1, 2-dichloroethane and m-xylene. However, when the leachate was prepared with these compounds present, considerable losses occurred in the irrigation system, and it proved impractical to apply these substances to the lysimeter at a constant nominal concentration which could be reproduced. This suggests that volatile organic compounds would rapidly be lost from leachates under actual landfill conditions. Irrigation of the remaining substances has continued, and though the microbial activity is reduced compared to that observed in the lysimeter receiving leachate (c), there is no evidence of any significant quantity of phenols or aniline in the uppermost suction probe. Considerable microbial activity has occurred in the upper layers of the lysimeter receiving leachate (c) and this has resulted in blocking of the surface by a profuse mixed fungal and bacterial growth. The acetate in this leachate is being completely degraded, though the rate of this reaction is temperature-dependent. Chloride and sulphate are not attenuated, but there is evidence that both ammonium and potassium ions are being utilised by the microbial population.

ii. Chalk

For studies on the Chalk, the experimental site is located at Harwell, Oxfordshire, and consists of an exposed circular area of Lower Chalk in which a central pumping borehole was constructed. The approach used was to apply water containing a radioactive tracer (eg Bromine 82) to the exposed Chalk surface, and to monitor the output of the central borehole for the presence of the tracer after it had migrated downwards through the unsaturated zone to the water table. Because of exceptionally low levels of the water table during the period of these experiments, owing to the prolonged dry condition in recent years, the amount of information obtained has been rather limited. It is, however, hoped to obtain data relevant to the problem of establishing the mechanism of groundwater flow through unsaturated chalk.

iii. Gravel

Although a site has been selected for this investigation, and some preliminary experiments undertaken, no detailed results were available in time to be included in this report. An initial irrigation experiment using radioactive tracer (Bromine 82) to determine rates of transport and dispersion through the gravel was carried out. Subsequently, irrigation with an aqueous solution containing sodium, lithium and zinc was commenced, and their attenuation is being followed using a network of boreholes in and around the research site.

iv. Monolith lysimeters

Undisturbed monolithic cores of sand, chalk and gravel have been obtained using a technique originally developed for Euratom at Wageningen, Netherlands, and applied by the Agricultural Research Council at Letcombe Regis, Oxfordshire. The cores have a depth of 1.35m and diameter of 0.8m, and are thus intermediate in size between laboratory columns and field lysimeters. Using similar instrumentation and artificial leachates to those studied in the field-scale experiments, these monoliths are being operated for comparison of attenuation effects with respect to both the laboratory and field-scale investigations.

v. Laboratory-scale experiments

Small columns of disturbed sand have been operated under both unsaturated and saturated flow conditions, to evaluate techniques and equipment before use in the field lysimeter experiments, and to assess the use of laboratory-scale experiments for investigating the behaviour of contaminants in the unsaturated zone. Such experiments would, if the results were consistent with those obtained in the field, provide a more rapid and less costly means of acquiring the necessary information.

4. Mathematical modelling

Within the main landfill research programme a limited effort on mathematical modelling has been included, to assist in interpreting the results obtained from laboratory and site investigations and to assess the usefulness of modelling as a predictive technique for landfill management. This effort has concentrated on three topics:

i. Assessment of the volume and composition of leachate reaching the base of a landfill.

A technique for predicting the quantity and quality of leachate at the base of a landfill site, from a knowledge of the type and behaviour of the wastes in the site and other information such as meteorological data, is being developed. The final format and method of application of the technique have not yet been decided; one possibility might be to use it as an aid in making day to day decisions for management of landfill sites, for example to decide whether or not a particular waste should be landfilled at a given site.

ii. The unsaturated zone.

Because of the wide range of conditions in this zone, the amount of data needed to model unsaturated flow is considerable, and it may not be possible to obtain all the necessary information from the landfill site investigations. Instead, the approach used in modelling this zone has been to regard it as a delay mechanism affecting the downward movement of leachate from the landfill to the water table. Using this approach, field measurements have provided relevant information for Chalk, and additional data for sandstones will be obtained from another research programme on the presence of nitrates in groundwater.

iii. The saturated zone.

In this zone, two separate aspects have been considered.

Firstly, where the local geology is not too complex, mathematical models of actual landfill sites can be developed using data obtained from site investigations to provide predictions of contaminant migration and to assist in planning future monitoring programmes. This technique is being applied to the Coatham Stob landfill site (see para 1.a), but full results are not yet available.

Secondly, models of idealised, hypothetical landfill sites have been used to predict the effects of dilution and dispersion in groundwater on the leachates leaving the site. This work is particularly aimed at estimating the concentrations of individual components of landfill leachates that may enter groundwater and may appear in boreholes or wells used as sources of public water supply. These models can also be used to forecast the times of travel of contaminants from landfill sites to surface streams or to boreholes located at differing distances from the sites. The information needed for the models is being obtained both from general hydrogeological, theory and from field measurements of the properties of important aquifer materials. Preliminary results of the use of such models were reported in a paper presented at a recent conference on groundwater (34).

III. 1.7 UNITED STATES

A wide-ranging programme of landfill research has been commenced, the work being mainly sponsored by relevant divisions of the Environmental Protection Agency:

1. The Solid and Hazardous Waste Research Division (SHWRD)
2. The Office of Solid Waste Management (OSWM) of the Hazardous Waste Management Division

The SHWRD programme is directed towards new and improved systems of solid and hazardous waste management, including the development of technology, the determination of environmental effects, and the collection of data necessary for the formulation of guidelines for processing and disposal. The research is divided into two general areas: (i) landfill disposal of hazardous wastes, (ii) hazardous waste materials treatment. The principal individual project areas are:

Identification and characterisation of hazardous waste

Hazardous waste decomposition

Pollutant migration through soils

Control technology

Disposal problems of specialised wastes

Alternatives for hazardous waste landfills

The OSWM programme comprises a variety of studies and demonstration projects designed to provide basic data and support for the formulation of standards, regulations and guidelines for the treatment and disposal of hazardous wastes. The work includes laboratory and site investigations, and some individual projects are as follows:

Development of a standard leaching test

Development of a standard attenuation procedure

Monitoring of groundwater quality at hazardous waste disposal sites

Construction and demonstration of a chemical waste landfill facility

Not all of the above projects will be completed within the time-scale of the present CCMS Pilot Study. However, outlines of the contents of these programmes were given by the US delegation at the London meeting of experts in October 1975 (35, 36, 37) and further reports were presented (38, 39) at a hazardous waste research symposium held at Tucson, Arizona in February 1976. The following descriptions of individual projects are based on papers presented at these two meetings.

I. SHWRD Projects

1. Identification of input to landfill sites

The project aims to produce a detailed analysis of the types, amounts, and characteristics of hazardous waste disposed of by landfill in the industrial region of southern California, and to apply the findings to other areas where similar wastes arise from industrial processes. Representative samples of each consignment of waste received at the selected landfill sites will be taken and subjected to detailed chemical analysis, and together with records of the amounts and types of waste received at each site will be used to estimate the annual volume and mass for each waste and pollutant deposited at the sites.

2. Waste decomposition in landfills

A study of the factors influencing (a) the rate of decomposition of solid municipal waste in a landfill site, (b) the quantity and composition of gas and leachate produced during decomposition, and (c) the effect of admixing industrial and sewage sludges with municipal refuse, is being conducted at the EPA Center Hill Research Facility in Cincinnati, Ohio. The method adopted uses test cells consisting of epoxy-lined steel cylinders of 1.8m diameter and 3.6m length, containing municipal refuse (to a depth of 2.4m) and compacted soil (0.6m). Some of the test cells are buried in the ground outdoors; others are located inside a temperature-controlled laboratory. All of the cells receive only the moisture applied as part of the experiments, and are arranged so that the leachate produced can be collected and measured. Both aerobic and anaerobic modes of operation are used and the cells are fitted with sensors for measurement of temperature; probes are also provided to enable gas samples to be withdrawn for analysis.

The experimental variables were chosen so that information would be obtained on the following:

i. the total amounts, rates of production and composition of gases and leachate produced during decomposition,

ii. the settlement rate,

iii. the survival of added poliovirus in the refuse and the leachates produced from the refuse,

iv. the effect of co-disposal of different wastes on the decomposition process.

3. Pollutant migration through soils

Several studies aimed at understanding and predicting the extent of migration of contaminants, particularly heavy metals, through soils at disposal sites used for municipal and hazardous wastes have been undertaken. The work includes both laboratory and field investigations:

i. Contaminant attenuation in whole soils has been studied by passing municipal leachate to which high concentrations of metal ions were added through columns of whole soils, containing a variety of organic and inorganic substances and maintained in a saturated, anaerobic state. The most significant factors were then inferred from correlation of observed migration rates and the known characteristics of the soils and contaminants. This research has been carried out at the University of Arizona. Preliminary findings were that

a. the clay content and the surface area per unit weight of the soils were the most important factors governing attenuation of metals but other factors such as iron oxide content were identified;

b. the least generally mobile were Pb and Cu, the most Cr, Hg and Ni, whilst As, Be, Cd, Se, V and Zn varied;

c. increasing flow rates of leachate decreased attenuation;

d. subsequent leaching of portions of the columns with water released only minimal quantities of attenuated ions whilst dilute acid leaching gave significant removal.

Work is continuing with a study of the value of using several lining materials such as agricultural limestone, iron-oxides, lime-sulphur oxide and organic wastes.

ii. The removal of contaminants from landfill leachates by soil clay minerals has been investigated by the Illinois State Geological Survey. The technique used was to pass municipal refuse leachate (with and without added metals) through soil columns packed with mixtures of quartz sand and clay minerals. Both sterilised and unsterilised leachates were used in order to study the effect of microbial activity on hydraulic conductivity, and the uptake of contaminants from leachate by the clay minerals as a function of pH and leachate composition was also investigated. Hydraulic conductivity decreased over several months for columns containing material of lower clay content particularly when unsterilised solutions were applied. Heavy metals in cationic form were much more strongly attenuated than those present as anions. The ranking of clay minerals according to their attenuation capacity followed the order of their cation exchange capacity and surface area, as montmorillonite > illite > kaolinite. Precipitation mechanisms are thought to be largely responsible for retention of the heavy metals except at lower pH when CEC becomes more important. Some suggestions were made for the amount of clay lining materials that would prevent the movement of various metals if present in leachate from landfill sites. Low pH should be avoided for maximum retention of metals when in cationic form.

iii. The potential for contaminant migration from several types of hazardous industrial wastes that may be disposed of to land is being studied at the US Army Dugway Proving Ground. In this research, after the composition and leachability of the waste has been established, a leachate from the waste is applied to columns of soils in the laboratory to obtain information on the rates of movement of various contaminants. The soils used in this work were selected from among those used in project (i), and the wastes include for example electroplating wastes, inorganic pigments, lead-acid and nickel-cadmium batteries, and residues from petroleum re-refining. First results for the nickel-bearing wastes showed that the nickel concentrations in leachate obtained by passing water through the wastes were highest for arisings from nickel-cadmium battery production washings, substantial for electroplating wastes, but small for inorganic pigment and water-base paint wastes. After passage through a selected Davidson soil the nickel concentrations in the liquids were regarded as significant regarding landfill only for the first waste: analysis of the soil showed a high content of cadmium, and it appeared that its capacity had been exceeded by the input in that case. A little information was given for other types of soil.

iv. The migration and degradation in soil of the pesticides methyl parathion, 2, 4-D, atrazine, trifluralin and terbacil is being investigated at the University of Florida. In this work, the pesticides are applied to soil columns in the laboratory at much higher concentrations than those used in normal agricultural practices so as to obtain information relevant to problems encountered in the disposal of pesticide residues and containers to land. The project includes work on the adsorption, desorption, chemical and microbial degradation, migration rates and production of metabolites of the selected pesticides. This project is scheduled for completion in August 1977. The limited work reported so far has been with respect to 2, 4-Dichlorophenoxy acetic acid (2, 4-D).

v. Field verification of hazardous waste migration

The objective of this research, which is being conducted by the University of Illinois, is to test current assumptions about the effectiveness of clays and other fine-textured materials in restricting the movements of contaminants into groundwaters. The approach adopted has been to examine the patterns of contaminant migration around two secondary zinc smelting plants and an organic chemical manufacturing plant from which the wastes are either stored or disposed of to land. The soils in each area are fine-textured and from present knowledge are regarded as providing safe disposal sites. The project is scheduled for completion in early 1977. The reported work refers largely to the methodologies adopted. However, initial results for one secondary zinc smelting plant suggest that the higher zinc concentrations in soil are limited to areas directly beneath the cinder fill covering the plant property, and that in general zinc concentrations in water from all the well sampling points are less than 1 ppm.

4. Control technology

Within this research area several investigations of treatment methods for hazardous wastes or of protective measures for use at landfill sites have been commenced:

i. Development of a polymeric encapsulation technique for both fixing and coating hazardous materials including pesticides, soluble organic compounds and heavy oily residues is under way. The process relates to the fixing of material in a 200-litre drum or 200-kg block prior to encapsulating the drum or block with a non-porous plastic coating. The initial stage of the project deals with organic processes designed to effectively encapsulate hazardous wastes into a relatively dense mass which will not pollute and could be utilised or disposed of in road beds, mines or landfill sites.

ii. Evaluation of available processes for stabilisation or chemical fixation of five types of industrial waste. The initial stage of this work consists of converting the wastes into an insoluble or sparingly soluble form, which is then subjected to leaching and physical testing to determine its chemical and physical stability. Samples of the untreated waste are also examined to provide baseline data. From the results of these initial laboratory tests, the most promising processes will be identified and then subjected to further evaluation using large-scale field plots or lysimeters.

iii. Studies of liner materials for both municipal and hazardous waste landfill sites. The specific objectives of these studies are (a) to determine the effects of leachates from the wastes on the physical properties of the liner materials, (b) to estimate the effective life of the liner materials when subjected to prolonged exposure from leachates, and (c) to obtain information on the costs and effectiveness of the liner materials. Three types of wastes are being used in these studies: municipal solid waste, hazardous wastes (the actual types have yet to be selected), and sludges produced by the removal of oxides of sulphur from the flue gases of coal-burning generating stations. The types of liner material which will be evaluated include polymeric membranes, admixed materials, and sprayed-on materials. (see also section II. 2.2.)

5. Disposal problems of specialised wastes

i. Hexachlorobenzene (HCB) disposal: an evaluation of the effectiveness of the procedures currently used to seal landfills containing hexachlorobenzene wastes, by measuring the rate of movement of HCB through soil water, and polyethylene film. The general approach is to measure the steady-state vapour flux of HCB under laboratory conditions, and then by using Fick's first law to calculate the diffusion coefficient of HCB in that material. From the diffusion coefficient, the flux through other thicknesses of the material can be calculated and the results used to specify acceptable conditions, if any, for the storage or disposal of HCB-containing wastes to land.

ii. Vinyl chloride monomer (VCM): process wastes from the production of polyvinyl chloride may contain VCM which, if disposed of to land, may present a potential threat to site operators or to nearby residents. The research aims to determine the amounts of VCM present in the wastes and to investigate their potential for producing (by volatilisation) emissions containing VCM in harmful concentrations.

iii. Oil spill debris: disposal of oil-contaminated residues produced during clean-up operations is being studied to determine the best practicable technical options; the work aims to produce and demonstrate suitable handling techniques for these materials.

6. Alternatives for hazardous waste landfills

As an alternative to landfill disposal, the application of oily wastes either directly to or admixed with soils has been practised for many years; the technique is known as land cultivation. Since many industrial waste sludges have similar characteristics to oily wastes, it is possible that the technique of land cultivation may provide a valid alternative to landfill. Initially, the research aims to review the present status of land cultivation, to assess the technical and economic feasibility of applying the technique to hazardous industrial wastes, and to develop background data for RCRA.

II. OSWM Projects

1. Development of a standard leaching test (SLT)

The objective of this work is to develop standard laboratory procedures which could be used to determine the amounts of hazardous constituents that could be potentially leached from particular types of industrial waste. The results of this work will be used to aid in identification of potentially hazardous wastes along with other data such as toxicity, volatility, flammability and soil attenuation behaviour. The approach adopted is to subject the selected wastes to extraction procedures using a range of aqueous and organic solvents. Completion of the work is scheduled for Spring 1977.

2. Development of a standard attenuation procedure (SAP)

Once it has been shown from the results of standard leaching tests that a waste contains significant concentrations of leachable hazardous constituents, further information is needed to select a suitable disposal site. The SAP is intended to provide the additional information by predicting the groundwater pollution potential of the waste, based on the characteristics of the disposal site and the wastes to be disposed of. It is envisaged that the development of an SAP test will comprise the following stages:

i. identification of available techniques and those under development,

ii. assessment of possible techniques for development of a standard procedure,

iii. development and evaluation of the selected technique or combination of techniques.

Completion of Part I of the work is scheduled for spring 1977.

3. Monitoring of groundwater quality at hazardous waste disposal sites

The work consists of determining the present patterns of groundwater contamination in and around a representative selection of landfill sites where industrial wastes have been deposited, and of monitoring changes in groundwater quality. The main investigations will include construction of boreholes, and sampling and analysis of groundwater at up to 25 industrial waste landfill sites representative of differing hydrogeological conditions and containing significant quantities of a variety of industrial wastes. Desk studies of a further 50 sites using data previously obtained from existing monitoring wells and other sources will be carried out as an initial phase of this study. The project is not scheduled for completion until 1978.

4. Chemical waste landfill demonstration facility

This project, which is being undertaken by the Minnesota Pollution Control Agency, is intended to demonstrate the construction and operation of a landfill facility for chemical wastes, which could be used on a regional basis as alternatives to conventional landfill disposal. Such facilities could be operated as a joint venture between local government agencies and private industry. The technical and scientific aspects of the project include:

i. development of site selection methods,

ii. demonstration of appropriate site preparation techniques so as to prevent groundwater contamination,

iii. demonstration of monitoring and surveillance techniques,

iv. evaluation of waste handling and operational procedures,

v. determination of costs,

vi. evaluation of social and institutional aspects.

The whole programme is scheduled over a five-year study period and will not be completed until 1980.

III. Other work

Of the other work being carried out reference is made here only to that of Systems Technology Corporation, Cincinnati. A comprehensive study is being made of the leachates produced from domestic waste both alone and when mixed with several industrial wastes. The many preliminary results are difficult to summarise but in general (although there are exceptions) the concentrations of the individual measured parameters (eg organic acids, TOC, metals) did not differ by an order of magnitude amongst the various test cells.

III.2. Site Research Investigation Techniques

III.2.1. Preliminary site assessment

III.2.1.1. Collection of background information

Before commencing any site investigation which will involve the construction of boreholes and the sampling and analysis of materials present in them or in the site itself, it is worthwhile to obtain any relevant background information about the site that may be available. Possible sources of such information include:

i. Maps, plans and records from cartographic, geological and planning surveys.

ii. Site owners, operators and employees.

iii. Water supply authorities.

iv. Local industries.

v. Aerial photographic surveys.

III.2.1.2. Site visual inspection

The background information obtained from the desk study will usually be of a general rather than a specific nature. It should, however, enable the land area to be investigated to be identified reasonably closely, and may also provide some information on the distribution of wastes within the site. To supplement this information and to confirm the findings of the desk study a visual inspection of the site should be carried out and the observations recorded on a detailed plan. Depending on the types of waste present at the site, appropriate precautions should be taken by those carrying out the usual inspection; for example protective clothing and footwear may need to be used if the site is known to contain particularly hazardous wastes.

III.2.1.3. Preliminary sampling programme

The locations of the various types of waste within the site should be known approximately from the previous stages. If necessary, further confirmation may be obtained by excavating a series of trenches within the individual areas of waste deposition; the depths of the trenches being chosen according to requirements, and by examining samples obtained from various depths.

A series of shallow boreholes located in a grid pattern can also be used to confirm the area and depth of the landfill material and to recover samples from various depths for identification of the wastes present. The size of the grid will depend on many factors, including the area of the site, the variability of waste distribution, and the resources available for the investigation. A regularly located series of sampling positions will however assist in the interpretation of analytical data. In addition to the boreholes located within the site itself, a limited number of similar boreholes may be drilled outside the site boundary to below the local groundwater table; this will enable the local hydrogeologic gradient and direction of groundwater flow to be determined. Geophysical survey methods may also prove useful in supplementing the information obtained from the boreholes.

III.2.2. Detailed site investigation

III.2.2.1. Boreholes

Type and location

The location of boreholes for detailed study should be determined from the results of the preliminary site assessment. Boreholes both within and outside the site boundaries may be required, the former mainly to recover samples of the wastes present in the landfill, and the latter to obtain samples of local groundwater and to serve as monitoring points for surveillance of groundwater quality. In the site investigations carried out by the UK Water Research Centre, these two types of boreholes were designated Types A and B respectively (see Fig 5). Type A boreholes (those within the landfill itself) were sometimes extended into the underlying aquifer to within 5-10m of the water table, but were always backfilled and sealed after completion of sampling. Type B boreholes (outside the landfill) were commonly terminated at a depth of 20m below the water table. These boreholes were lined and remain open for continued sampling and observation of groundwater.

Methods of construction

For exploratory drilling, the necessary information concerning the presence and locations of hazardous wastes and the hydrogeological conditions at the site can be obtained by relatively rapid drilling techniques such as continuous flight augering. The purpose of the main investigation is to recover undisturbed core samples for examination, and for this more precise drilling methods are needed. Both air-flush rotary and drive coring methods have been used in the UK programme to suit differing geological conditions and satisfy sampling requirements. The use of drilling fluids during boreholes construction is undesirable, except where strictly necessary, to avoid contamination of interstitial water in the core samples or of standing water in the borehole itself. Detailed descriptions of construction methods and materials used in the UK programme were reported by Harrison (40).

III.2.2.2. Sampling and analysis of borehole materials

Recovery and examination of cores

Recovered rock cores are examined to distinguish changes in lithology and to identify zones of potentially high permeability within the rock. Determinations of properties such as porosity, centrifuged specific yield, and intrinsic permeability in both horizontal and vertical directions may be carried out on selected cores to obtain detailed hydrogeological data about the site. In the preliminary site assessment, these determinations may not be necessary since the main objective of this stage is to recover bulk samples of landfill material. For the main investigation, it is preferable to obtain undisturbed core samples from known depths, and the determination of hydraulic properties can then be carried out systematically, for example by sampling the cores at regular intervals (eg at 1-metre intervals).

Extraction of interstitial fluids from cores

Centrifugal extraction has proved a useful technique for investigation of groundwater contamination in porous consolidated rocks such as chalk and sandstone but is less useful for unconsolidated materials (41). Contamination of solid core samples and of interstitial fluids during drilling is almost unavoidable under normal field conditions. This has been shown by tracer tests using lithium nitrate solution during the UK site investigation programme,

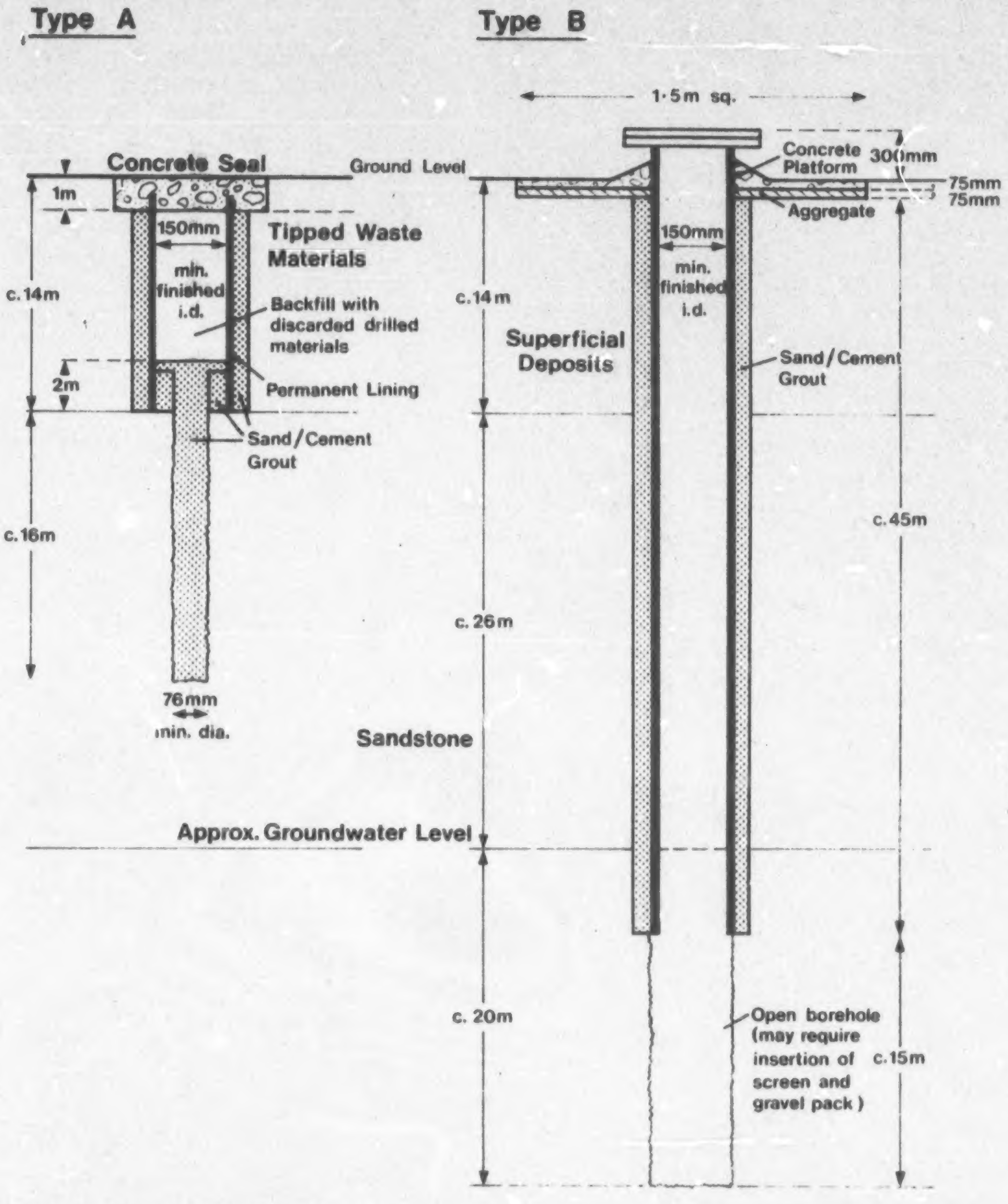

Type A
Type B
1·5m sq.
Concrete Seal
Ground Level
1m
150mm
Tipped Waste Materials
min. finished i.d.
c.14m
Backfill with discarded drilled materials
2m
Permanent Lining
Sand/Cement Grout
c.16m
76mm
min. dia.
Concrete Platform
300mm
75mm
75mm
Aggregate
150mm
min. finished i.d.
c.14m
Superficial Deposits
Sand/Cement Grout
c.45m
c.26m
Sandstone
Approx. Groundwater Level
c.20m
Open borehole (may require insertion of screen and gravel pack)
c.15m

Fig. 5 (sect.III.2.2.1.)
DETAILS OF BOREHOLES
Yew Tree Farm Landfill Site,
WILDMOOR, NR. BROMSGROVE, WORCS.

which indicated that the outermost 1-2 cm of 11-cm diameter rotary drilled cores were liable to be contaminated both by borehole waters and by oil from the drilling equipment. These parts of the cores should therefore be discarded and the detailed examinations carried out on the remaining central portions of each core. Only very small volumes of interstitial fluid are recovered from most cores; these small sample volumes restrict the range of chemical determinations that can be carried out, and usually only those parimeters of major importance for indicating groundwater contamination can be determined (for example TOC, chloride, ammoniacal nitrogen).

III.2.2.3. Sampling of groundwater and leachate

The volumes of groundwater and leachate available from the investigation boreholes are usually sufficient to permit the use of conventional water sampling equipment. Sample volumes in the range 500-2500 ml are typical and these enable a much wider range of chemical determinations to be carried out. It is then possible to obtain information on the variation of groundwater or leachate quality with depth. In addition, in-situ measurements of parameters such as dissolved oxygen and temperature can be made using sensors installed in the boreholes.

III.2.2.4. Detection and analysis of borehole gases

Portable gas detectors have been used for in-situ determinations of specific constituents of borehole atmospheres, for example methane, hydrogen cyanide and hydrogen sulphide. Such measurements may be necessary during the construction of boreholes at sites known to contain hazardous wastes, so that conditions which could present a risk to the safety of the drilling operators (eg explosivity or release of noxious fumes) can be monitored. Unless precautions are taken to prevent ingress of normal atmospheric gases, the results obtained by the use of gas detectors cannot be regarded as fully representative of the composition of borehole atmospheres.

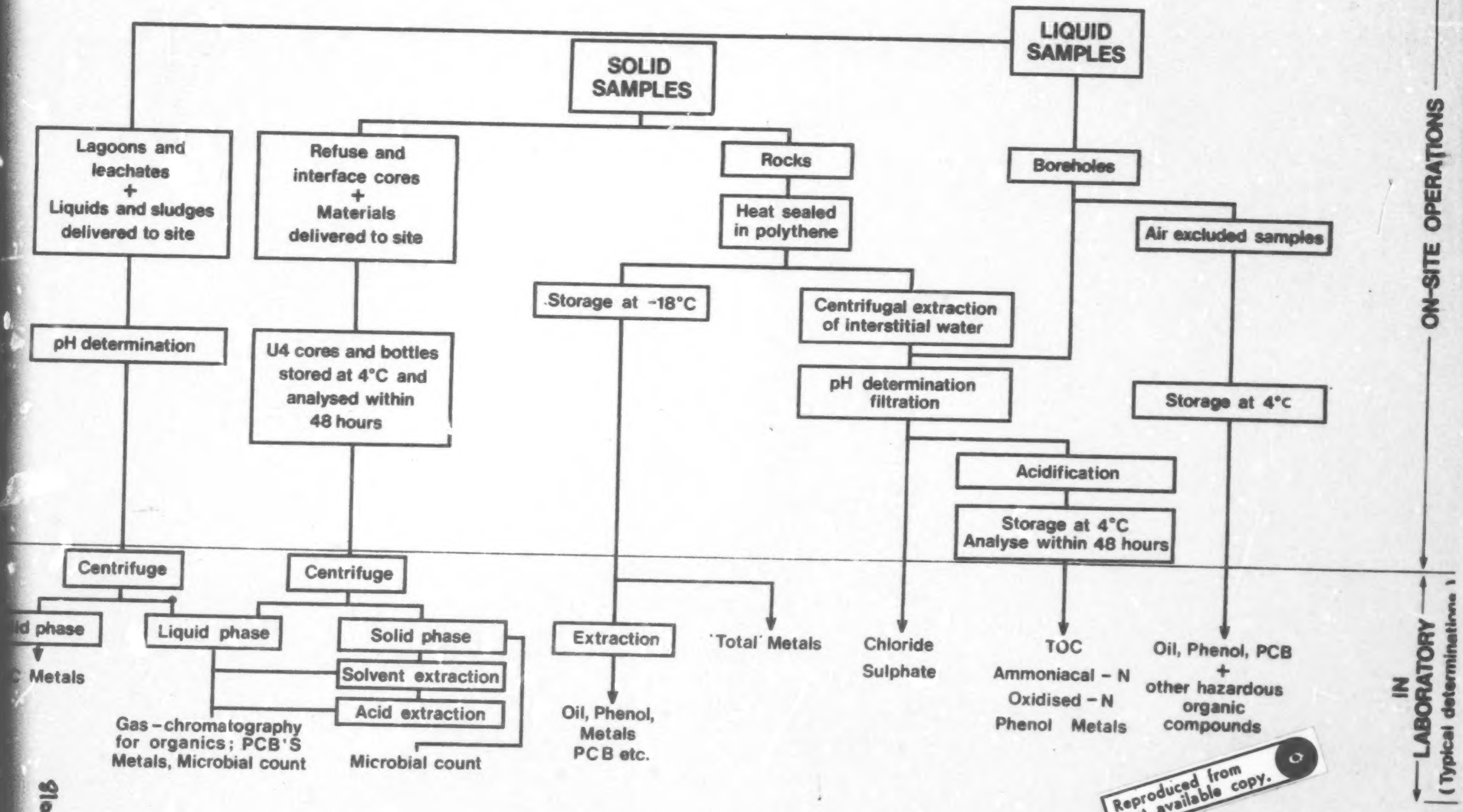
III.2.2.5. Analytical methods

As far as possible, samples collected during the main site investigation should be analysed immediately after recovery for example in an on-site laboratory. Where this is impracticable and storage of samples is unavoidable, both solid and liquid samples should be stored under cool conditions to minimise decomposition. In the UK programme, solid samples were kept at -18°C, no significant change in the concentrations of oil, phenols or halogenated compounds having been observed in test samples kept at this temperature for several months. Liquid samples, and solid samples from which interstitial fluids were to be extracted, were stored at 4°C. Only slight changes, for example loss of low levels of TOC and increase in sulphate concentration, were noted in samples of interstitial water obtained from chalk core stored at this temperature.

The range of determinations required will depend on the nature of the site and the types of wastes present. Typical determinations carried out during site investigations are shown in Fig 6. For most of these analyses, the procedures used will vary depending on the facilities available, but in all cases the methods of analyses should be stated when results are quoted; this being particularly important since many "standard" laboratory procedures will in fact require modification to be suitable for the types of samples recovered during landfill site investigations.

Reproduced from best available copy.

Fig. 6. Flow-chart summarising the scheme of sampling/analysis of liquid and solid samples from landfill site investigations (see sect. III.2.2. 5.)


LIQUID SAMPLES
SOLID SAMPLES
Lagoons and leachates + Liquids and sludges delivered to site
Refuse and interface cores + Materials delivered to site
Rocks
Heat sealed in polythene
Boreholes
Air excluded samples
pH determination
U4 cores and bottles stored at 4°C and analysed within 48 hours
Storage at -18°C
Centrifugal extraction of interstitial water
pH determination filtration
Storage at 4°C
Acidification
Storage at 4°C Analyse within 48 hours
Centrifuge
Centrifuge
id phase
C Metals
Liquid phase
Solid phase
Solvent extraction
Acid extraction
Gas-chromatography for organics; PCB'S Metals, Microbial count
Microbial count
Extraction
Oil, Phenol, Metals PCB etc.
'Total' Metals
Chloride
Sulphate
TOC
Ammoniacal - N
Oxidised - N
Phenol Metals
Oil, Phenol, PCB + other hazardous organic compounds
ON-SITE OPERATIONS
IN LABORATORY
(Typical determinations)

Reproduced from best available copy.

IV. CONCLUSIONS

1. The extent to which landfill and special chemical landfill of hazardous wastes is practised in participating countries varies, but in general at present it represents an important method of disposal in almost all of the countries and this situation is likely to continue for the foreseeable future. There are few alternative disposal methods having similar high capacity to cope with large volumes and the ability to deal with a wide range of wastes; landfill has the added advantage of making a contribution to land reclamation. However, these aspects may be of limited application for the more hazardous wastes.

2. In the countries which participated in this project, two main approaches to landfill have been adopted:-

   a. Landfill is regarded as one of a number of options for waste disposal, and forms part of the overall disposal strategy for various wastes including domestic, commercial, industrial and certain types of hazardous wastes. (This question of options is discussed in some detail in the report of the Sub-Project on Recommended Procedures for Hazardous Waste Management, carried out under the Pilot Study on Disposal of Hazardous Wastes).

   b. Where restrictions on landfill of chemical or hazardous wastes apply, usually by legislation or because only a limited number of sites are available, there may still be specified exceptions to the limitation.

3. Continued use, for hazardous waste disposal, of landfill and special chemical landfill to some extent by almost all participating countries seems to be a generally accepted principle, but because of the considerable geological, hydrogeological, topographical, climatological and population density differences between the participating countries it may not be possible to devise a single "management" approach to landfill of hazardous wastes for general use. What seems more probable is that countries will increasingly seek to optimise their use of landfill starting from one or other of the basic approaches mentioned above, and it is hoped that this project report, taken in conjunction with consideration of local conditions, will assist in reaching better-informed decisions.

4. The importance of avoiding harmful effects of landfills is recognised in all participating countries. The most important of the possible effects is generally agreed to be the potential risk of pollution of water resources, and in particular of contamination of groundwater. Relevant parameters with respect to water pollution include the properties of the wastes, such as solubility, acidity, any action as solvent, and chemical reactivity giving rise to different substances; also the capacity for absorption, adsorption, biological or chemical breakdown and ion-exchange processes which may exist in the landfill itself or in other materials encountered en route to any relevant waters; finally the use to which any such waters are put, and the dilution factors which they provide. Apart from water pollution matters attention must be paid to other aspects such as flammability, corrosivity, volatility and odour emission, these being considered, where appropriate, in the light of the circumstances of the particular landfill site.

5. The extent to which groundwater is used in participating countries for potable water supplies varies considerably, and in some countries it at present provides such supplies for a high proportion of the population. Where this situation coincides with a climate which increases the tendency for leachate generation, ie where there is a net annual soil moisture surplus, the protection of aquifers has to be considered.

6. In other regions where there is a net annual soil moisture deficit, the leachate generating potential of landfilled wastes may be smaller. The consequences of any movement of leachate should still be considered, since local aquifers which supply small private wells and boreholes could be at risk although there might be circumstances where it would be most appropriate to provide alternative supplies. However, in such regions the need is more likely to be for adequate control over the types and quantities of wastes accepted for landfill disposal (especially liquid wastes) rather than to prevent or minimise the effects of natural precipitation.

7. Examples of pollution both of surface and of ground waters due to landfill disposal of hazardous wastes have been reported by several participating countries. Where such incidents have been experienced, they seem usually to have been due to such factors as poor site selection, inadequate supervision, and incorrect methods of deposition as well as insufficient knowledge about soil-waste interaction in the underlying strata, rather than to basic unsuitability of landfill as a disposal route. With the advent of new legislation providing for hazardous waste control in many participating countries in the past few years it is anticipated that better hazardous waste landfill practice will be followed in the future.

8. Because of the continuing importance of environmental protection measures, in addition to the need to dispose of wastes safely to land, several countries have in recent years commenced extensive programmes of research into various aspects of landfill disposal. Such programmes are by nature fairly long-term studies, and it has not been possible within the time-scale of this project to examine the final conclusions of the various national programmes currently in progress. However, the project has provided opportunities for useful exchanges of information on landfill research topics, and it has been possible to include in this report some of the preliminary findings from the research programmes of several participating countries.

9. The wide range of topics and methods included in landfill research programmes are intended to provide the responsible authorities in each country with the guidance needed to develop future waste disposal policies, and to assist in defining the relevant legislative measures. From the large number of individual topics being investigated, it is perhaps possible to define three main areas of interest:-

a. How to minimise the leachate generating potential of wastes, and control the movement of any leachates that are produced within the landfill, and to study factors affecting movement of leachates away from the landfill.

b. How to select suitable sites for landfills, having regard to geological, hydrogeological and other relevant parameters.

c. What are the best methods for landfilling wastes of a particular type at a given site, including the extent to which co-disposal of different wastes can be used.

10. The leachate generating potential of wastes in landfill sites depends on natural precipitation and groundwater level, as well as on the properties of the waste itself and the method of its deposition in the landfill. Several projects have been commenced to investigate these relationships, and preliminary findings indicate that the quantity of leachate can be reduced by subjecting each layer of waste to a high degree of compaction and by applying layers of impermeable material (eg clay) at varying depths within the landfill.

Experiences in the Federal Republic of Germany and the Netherlands indicate that wastes deposited above ground level in the form of mounds can be more easily controlled with respect to production of leachate, and this method of deposition may be advantageous in areas having a naturally high water table, or where other environmental restrictions may apply.

11. Methods for collecting leachate, prior to its treatment to render it suitable for discharge, or to recirculating it through the landfill, are also being studied. By these techniques the quantity of leachate may be reduced and the composition of leachate may be modified, and its polluting potential reduced.

12. Although more work is still to be done, factors controlling the movement of leachates away from sites are beginning to be understood. These processes involve complex interactions between chemical, physical, biological and geological effects, and their effectiveness in attenuation of leachate contaminants provides the basis of the "attenuate and disperse" principle. The use of the landfill and the land itself in controlled chemical reactions also is an important area of study.

13. In most current investigations, the main objective appears to be the understanding of the processes governing movement of leachates at existing sites. When further information from field observation and laboratory studies is available it may then increasingly be possible to make predictions relevant both to those sites and to other sites for which some basic data is available. Already, however, there is substantial evidence from preliminary results of field investigations and laboratory/lysimeter research work to support the view based on experience that significant attenuating and recovery mechanisms apply, particularly when systems are not overloaded.

14. A supporting approach to the study of leachate generating potential consists of developing standard leaching procedures which can be applied to the testing of wastes before they are landfilled. Standard leaching test procedures are currently being studied by several member countries, but it seems likely that the nature, purpose, and status of these procedures, when details are finalised, may differ considerable between countries. Even when such procedures are available, a complete assessment of the problems due to leachate generation at a given site would still require a method for predicting attenuation characteristics for the leachate contaminants of particular interest, and as inferred in paragraph 13 at present such predictions are still somewhat limited in scope. However on occasions it is appropriate and useful to adopt a simple approach based merely on calculating the minimum dilution factor likely to apply to constituents of landfill leachate with respect to any relevant body of water; this gives a worse possible result for the concentration of constituents in receiving waters, with no allowance for the effect of any removal mechanisms, and may help at least to put a situation in perspective.

15. In connection with the selection of sites for use as landfills, application of the findings of research investigations is already being made in participating countries, and site selection criteria are being developed for use by authorities responsible for waste disposal. At present two main approaches seem to be used for selection of sites

a. Sites selected on the basis of their ability to contain wastes and leachates, especially from hazardous materials,

b. Sites which do not rely on containment, but which permit natural processes both within and outside the site to attenuate and disperse contaminants and to reduce concentrations of leachate components.

16. Sites relying on containment are typically those located on impermeable strata such as clays, but the ability of sites located on other types of strata to contain wastes and leachates can also be enhanced by the use of site liners. Collection and treatment of leachate must be accepted as a necessary part of a containment scheme. For disposal of particularly hazardous types of wastes in sensitive geological or hydrogeological areas containment may be essential, but use of such sites may in other situations be unnecessary.

17. Use of sites relying on containment for disposal of significant quantities of liquid wastes, or in areas of high natural precipitation, may cause problems in operation (such as difficulty in achieving a suitable liquid to solid ratio) and result in the build-up of a large volume of contaminated leachate within the site; stabilisation or restoration of the site after completion of landfill operations may involve extensive and costly remedial measures.

18. As mentioned in para 13, in recent years research into various aspects of the behaviour of wastes in landfill sites has shown that naturally-occurring processes both within and around sites can be effective in reducing or eliminating any environmental impact of waste disposal. The availability of such evidence has led to the development of an alternative approach to site selection, which may be termed the "attenuate and disperse" concept. Sites selected according to this approach need not rely on containment, but allow leachates to migrate away at slow rates which permit the various natural processes to act together to minimise the pollution potential of wastes. Local considerations, including the use which is likely to be made of any aquifer, and its value in a wider context, will obviously be important in deciding to what extent this approach can be adopted; however among the significant advantages it offers over the containment principle are the greater flexibility of operation, the avoidance of long-term site stabilisation or restoration problems, and the avoidance of collection and treatment of leachate.

19. The most favourable conditions for effective leachate attenuation are likely to occur in strata in which groundwater flow is intergranular and having a significant adsorption or cation exchange capacity; the existence of a relatively thick unsaturated zone is also advantageous. Many strata which provide these conditions are also valuable aquifers, for example in the United Kingdom the Lower Greensand, Lower Chalk and Bunter Sandstone, but with suitable precautions this does not necessarily preclude use of these areas for controlled landfill of some hazardous wastes.

20. Preliminary research results from the various programmes described in this report, together with experience from many existing sites, suggests that the "attenuate and disperse" principle may in some cases have advantages on environmental and technical grounds to the "containment" approach. Nevertheless some countries still have substantial reservations about attenuation and similar effects, for example in the Federal Republic of Germany the present tendency is towards leachate containment and control especially at special waste landfills. Further results obtained from landfill research programmes will permit more detailed guidance on site selection to be provided, so that whichever approach is adopted the possibility of selection of unsuitable sites should be eliminated. When considering the appropriate means of disposal of wastes, including the selection of landfill sites, it is important that all the various interests are balanced against each other, and the best available option chosen. Before rejecting a proposal for landfill it should be established whether the alternative is likely to involve markedly less risk or to be markedly less damaging to the environment, taking into account all forms of pollution including air pollution, traffic and damage to visual amenity; and whether extra cost (including the additional use of energy as well as the cost of transporting the waste to a more distant site) is justified by a commensurate lessening of risk or damage. Socio-political attitudes in the different countries are also relevant.

21. Methods of disposing of particular wastes at landfill sites, and site operational techniques in general, have not yet been studied systematically during investigations, but a few projects are currently in progress in member countries. Studies of specific site operating practices, such as disposal of sludges, incorporation of liquids, and handling methods for drummed wastes, might yield results capable of general application between countries.

22. Of particular importance is the extent to which co-disposal of domestic and industrial (including certain types of hazardous) wastes is applicable. At present co-disposal is not practised in some countries, but in others is used to varying degrees and in some is being extended. Continued use of landfill in participating countries seems likely to involve substantial quantities of wastes other than from domestic sources, so that authorities will increasingly need to consider possibilities for co-disposal in their waste management policies to ensure that sites are operated in the optimum manner.

23. Co-disposal would not be appropriate for wastes with considerable recovery potential, nor for particularly hazardous wastes which might endanger public safety and the environment, but for a wide range of other wastes there is in fact considerable scope for co-disposal in landfills. Much industrial waste is of similar characteristics to domestic waste and can be dealt with by similar controlled tipping techniques. Some other types, such as liquid wastes and sludges, can be incorporated by making use of the absorptive capacity of domestic waste when hydraulic conditions are favourable. There are also substantial quantities of inert industrial wastes, for example spoil, ashes, sands and slags, which are suitable for use as cover materials and are used in several countries.

24. The results of both experience and research work stress the importance of correct operating procedures at landfill sites, eg the avoidance of disposing of acids in situations which might lead to enhanced solubility of toxic chemicals, or the production of hazardous gases; the maintenance of a satisfactory balance between liquid and solid wastes is important if use is intended to be made of the absorptive capacity of the latter.

REFERENCES

1.	U K DELEGATION	Note on Sub-Project on Landfill Disposal. Plenary Meeting of CCMS Pilot Study on the Disposal of Hazardous Wastes, Bonn, FRG, May 1976.*
2.	VAN VEEN, F	Treatment of Chemical Wastes, including Legal Aspects. Paper presented at ISWA. Second International Congress, Padua, Italy, June 1976. SVA/1825.
3.	U K DELEGATION	Notes on Water Pollution Problems caused by Landfill Sites in the UK. Paper 1A, CCMS Experts Meeting of Sub-Project on Landfill Disposal, London, UK, October 1975.**
4.	U S ENVIRONMENTAL PROTECTION AGENCY	Hazardous Waste Disposal Damage Report, No 1, June 1975. EPA/530/SW-151
5.	U S ENVIRONMENTAL PROTECTION AGENCY	Hazardous Waste Disposal Damage Report, No 2, December 1975. EPA/530/SW-151.2
6.	U S ENVIRONMENTAL PROTECTION AGENCY	Hazardous Waste Disposal Damage Report, No 3, May 1976. EPA/530/SW-151.3
7.	BIRK, F et al	Die Auswirkungen der Verkippung und Lagerung von cyanidhaltigen Hartesalzen in Bochum - Gerthe auf des Grund-und Oberflachenwasser. Zeitschr. der Deutschen Geologischen Gesellschaft 1973 124 461-473.
8.	GRAMMEL, U	Uber die Auswirkungen einer Salzschlackeablagerung auf das Grundwasser. Gwf - Wasser/Abwasser 1972, 113 113-116.
9.	BALKE, K D et al	Chemische und thermische Kontamination des Grundwassers durch Industriewasser. Zeitschrift der Deutschen Geologischen Gesellschaft 1973, 124, 447-460.
10.	GOLWER, A et al	Belastung und Verunreinigung des Grundwassers durch feste Abfallstoffe. Abhandlungen des Hessischen Landesamtes fur Bodenforschung, Heft 73, Wiesbaden 1976, 131 pp.
11.	U K DELEGATION	Introductory Paper on UK Landfill Research Programme. Paper 1, London Meeting.
12.	U K DEPARTMENT OF THE ENVIRONMENT	Interim Report on Progress, Programme of Research on the Behaviour of Hazardous Wastes in Landfill Sites, September 1975.

---

* : subsequently referred to as "Bonn Meeting"

** : subsequently referred to as "London Meeting"

13.	ENVIRONMENT CANADA (ENVIRONMENTAL PROTECTION SERVICE)	Discussion on Procedures for Landfill Gas Monitoring and Control, January 1977. Proceedings to be published.
14.	U K DEPARTMENT OF THE ENVIRONMENT	Halogenated Hydrocarbon Solvent Wastes from Cleaning Processes. Waste Management Paper No 9, HMSO, London, 1976, 16pp.
15.	STRENG, D R	The Effects of the Disposal of Industrial Waste within a Sanitary Landfill Environment. Proceedings of Hazardous Waste Research Symposium, Tucson, Arizona, USA, February 1976, pp 51-70; Published by US Environmental Protection Agency, EPA 600/9-76-015, July 1976.
16.	CANADIAN DELEGATION	Solid Waste Management Branch Programmes relating to Industrial or Hazardous Wastes. Paper 8, London Meeting.
17.	CANADIAN DELEGATION	Program on Landfilling of Solid and Hazardous Wastes. Paper 8A, London Meeting.
18.	CANADIAN DELEGATION	Procedures for the Analysis of Landfill Leachate Environment Canada, Environmental Protection Service : Solid Waste Management Branch Report EPS-4-EC-75-2, October 1975, 26pp. (Presented as Paper 8B, London Meeting.)
19.	CANADIAN DELEGATION	Solid Waste Landfill, Landfill Leachate, and Industrial Waste Disposal Research Program. Presented at Bonn Meeting.
20.	ENVIRONMENT CANADA (ENVIRONMENTAL PROTECTION SERVICE : SOLID WASTE MANAGEMENT BRANCH)	Recommended Groundwater and Soil Sampling Procedures. Report EPS-4-EC-76-7, June 1976.
21.	E V S CONSULTANTS LTD (FOR ENVIRONMENT CANADA, ENVIRONMENTAL PROTECTION SERVICE)	Leachate Toxicity Measurements using the Residual Oxygen Bioassay Method. Contract Report OSS5-2025, December 1975.
22.	F R G DELEGATION	Experience with Joint Deposition of Residential and Industrial Waste with Experiments carried out in the Ruhr District. Paper 6B, London Meeting.

23.	F R G DELEGATION	Practice and Control of Landfill with Hazardous Wastes : Examples from the Federal Republic of Germany. Paper 6, London Meeting.
24.	F R G DELEGATION	Experiences and Research at the Berlin-Wannsee Waste Dump. Paper 6A, London Meeting.
25.	F R G DELEGATION	Progress in Landfill Research in the FRG. Presented at Bonn Meeting.
26.	-	Sickerwasser aus Mulldeponien Seminar : Stadtereinigung K G Edelhoff, 586 Iserlohn, April 1974, 104pp.
27.	-	Reinigung von Sickerwasser aus Mulldeponien Seminar : Stadtereinigung K G Edelhoff, 586 Iserlohn, July 1974, 96pp.
28.	SCHOTTLER, U	Die Reinigungswirkung von Boden am Beispiel von Schwermetallen. Zeitschrift der Deutschen Geologischen Gesellschaft 1973, 124, 555-566.
29.	FEIGE, W	Bodenkundliche Untersuchungen nordwestdeutscher Standorte zur geordneten Abwasserfaulschlammdeponie. Gottinger Bodenkundliche Berichte, Institut fur Bodenkunde, Universitat Gottingen, 1975, No 32. 144pp.
30.	KOTZIAS D, et al	Vorkommen von Xenobiotika im Sickerwasser. von Mulldeponien. Chemosphere 1975, 4, 301-306.
31.	LOHMEYER, S	Resistenz von Galvanik - und anderen Abwasserschlammen gegen Atmospharilien in einer geordneten Industrieschlamm - Deponie. Galvanotechnik 1974, 65, 759-768.
32.	BRADKE, H J, and KLEIN, T	Deponieverhalten und Verwertung von Giessereisanden, Teil I. Institut fur gewerbliche Wasserwirtschaft und Luftreinhaltung e V, Koln, 1975, 151pp.
33.	U K DELEGATION	Recent Progress in the UK Landfill Research Programme. Presented at Bonn Meeting.
34.	OAKES, D B	Use of Idealised Models in predicting the Pollution of Water Supplies due to Leachate from Landfill Sites. Paper 16, Conference on Groundwater Quality, Measurement, Prediction and Protection, University of Reading, September 1976. (Proceedings to be published by the Water Research Centre.)

35.	UNITED STATES DELEGATION	Research on minimising Environmental Impact from Landfilling. Paper 2, London Meeting.
36.	UNITED STATES DELEGATION	Landfill Related Projects. Paper 3, London Meeting.
37.	UNITED STATES DELEGATION	Research on Contaminant Movement in Soils. Paper 4, London Meeting.
38.	SCHOMAKER, N B	Current Research on Land Disposal of Hazardous Wastes. Source as for ref 12, pp 1-13.
39.	LINDSEY, A	OSWMP Chemical Waste Landfill and Related Projects. Source as for ref 12, pp 14-31.
40.	HARRISON, I B	Construction of Investigatory Boreholes in Landfill Sites. Surveyor, 1976 (25 June), 22-24.
41.	EDMUNDS, W M, and BATH, A N	Centrifuge Extraction and Chemical Analysis of Interstitial Waters. Environ. Sci. Technol. 1976, 10, 467-47